GOOD PRACTICES IN SLUDGE MANAGEMENT

PURE
project on urban reduction of eutrophication

Baltic Sea Region
Programme 2007–2013

Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

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Other authors and editors: Jan-Eric Luft, Entsorgungsbetriebe Lübeck; Tuuli Ojala, John Nurminen Foundation; Lotta Ruokanen, Helsinki Commission; Olena Zinchuk, Union of the Baltic Cities Environment Commission.

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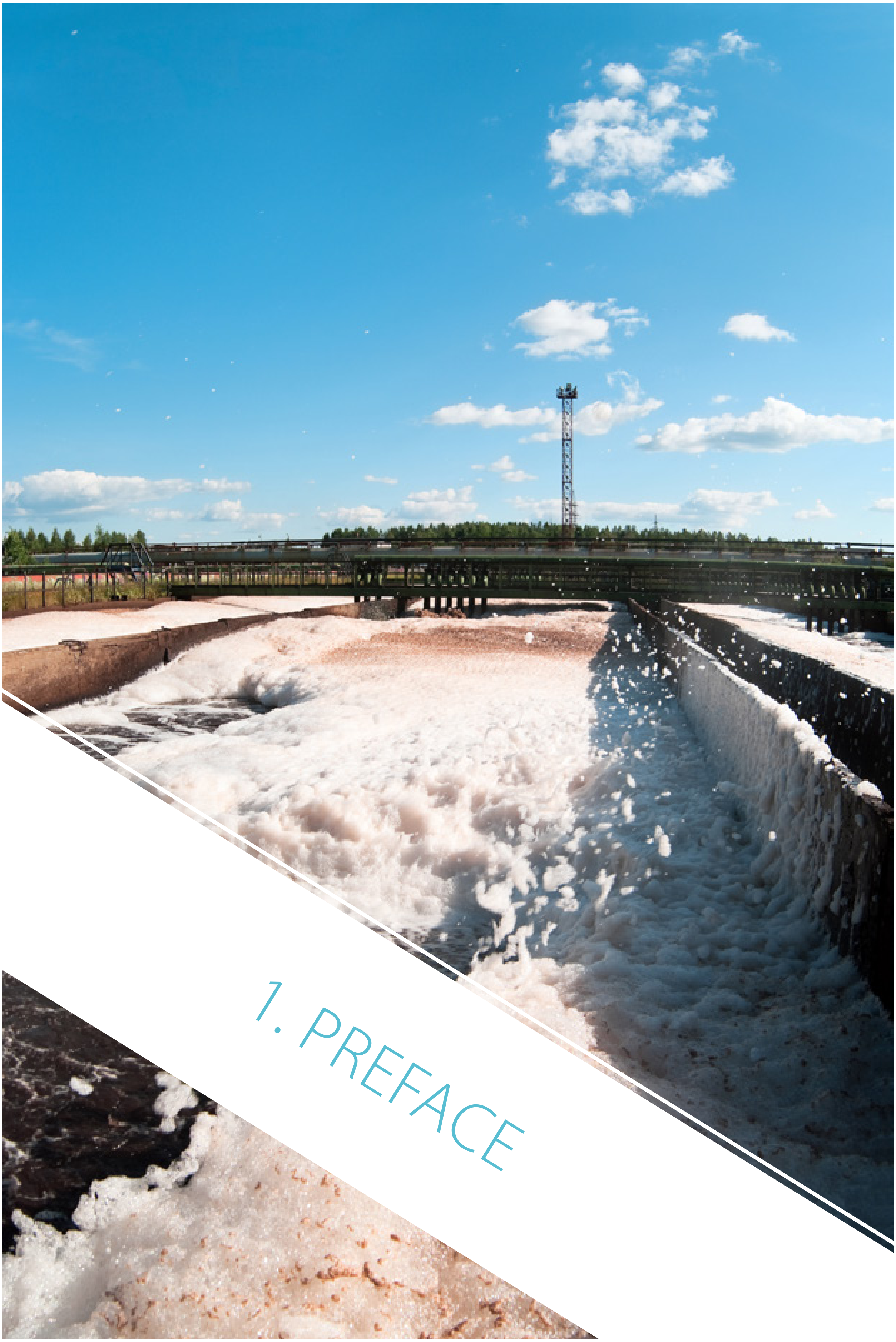
1. PREFACE



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1.1 Project on Urban Reduction of Eutrophication (PURE) IMPROVING MUNICIPAL SLUDGE MANAGEMENT

The Project on Urban Reduction of Eutrophication (PURE) aims at reducing the phosphorus loads that enter the Baltic Sea in excess amounts resulting in many negative consequences in the sea's ecosystem. PURE has proposed and realised cost-effective investments and operational changes to enhance phosphorus removal at six municipal waste water treatment plants. In addition, the project has reviewed good practices and challenges in municipal sewage sludge handling in the Baltic Sea region in order to facilitate decision making of the water companies in sludge management issues.

The description of sludge handling and disposal processes, possible sludge management problems and future plans of PURE partner and associate partner water companies were collected during the project. A PURE sludge handling workshop in September 2011 showcased some of the most advanced technologies in use in the leading country Germany. The alternative technical solutions and legislative situation concerning different ways of handling and disposing of sludge are compiled in this Book of Good Practices, including the differences in national trends and the status of emerging technologies.

Figure 1-1. Photo: Shutterstock.com/PanicAttack.

This publication presents the basics of sludge generation and management in modern urban waste water treatment. It also presents technical solutions used in sludge thickening, digestion, dewatering, hygienisation, drying and incineration as well as disposal. The technical review includes practical summaries and compares the results achievable with different techniques; maintenance requirements; capacity; applicability for different-sized treatment plants; examples of use in the Baltic Sea region and the costs; energy use; and possible chemical consumption. In addition, some relevant emerging technologies in reject water treatment and the recovery of phosphorus, for example, are explored.

The publication also includes observations concerning the main drivers and obstacles of sustainable sludge management, including both economic and regulatory drivers guiding the development of sludge management choices of an individual water company. Finally, some conclusions on the recommendable ways to manage urban waste water sludges are made.

1.2 TOWARDS A COMMON RECOMMENDATION IN SLUDGE MANAGEMENT IN THE BALTIC SEA REGION

The Baltic Marine Environment Protection Commission (Helsinki Commission or HELCOM) is one of the PURE partners. It works to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

HELCOM is the governing body of the "Convention on the Protection of the Marine Environment of the Baltic Sea Area" – more usually known as the Helsinki Convention. HELCOM's vision for the future is a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities.

The countries are committed to HELCOM's Baltic Sea Action Plan's (HELCOM, 2007) objectives to drastically reduce eutrophication by 2021, including implementing specific measures to improve the treatment of waste water. Recommendation 28E/5 'Municipal wastewater treatment' (HELCOM, 2007) specifies the requirements for sewage treatment which are stricter, for example, than the EU Urban Wastewater Directive (see chapter 12 for legislation). Reaching the HELCOM recommendation in phosphorus removal at the project partners' waste water treatment plants is the main objective of the PURE project, alongside improving sludge handling practices. No HELCOM recommendations currently exist for sewage sludge management.

HELCOM's Land-based Pollution Group (LAND) is responsible for reducing pollution from all land-based sources within the Baltic Sea catchment area. It identifies the point and diffuse sources of land-based pollution by nutrients and hazardous substances, and proposes suitable actions to reduce these emissions and discharges. At it's regular meeting in 2012, the LAND group supported, in general, the idea of revising HELCOM Recommendation 28E/5 to either include a sewage sludge handling component or develop a separate HELCOM recommendation on sewage sludge handling. The meeting welcomed the offer by Germany and Sweden to coordinate drafting of such a revised/new recommendation.

Figure 1-2: There are nine coastal countries around the Baltic Sea. The drainage area or catchment of the sea – which is home to over 85 million people – extends even wider and is almost four times larger than the sea itself (indicated in the map with a thick black line). Baltic Sea is much shallower than most of the world's seas, with a mean depth of only 53 m. It is very sensitive to impacts of human activities also because of the brackish water, cold winters and slow water exchange.

PURE Project partners

Union of the Baltic Cities, Commission on Environment

Union of the Baltic Cities (UBC) is a voluntary, proactive network mobilizing the shared potential of over 100 member cities for democratic, economic, social, cultural and environmentally sustainable development of the Baltic Sea Region. Union of the Baltic Cities Commission on Environment (EnvCom) is one of the 13 commissions of the UBC. It is responsible for the Union's work on environmental and urban sustainability. In PURE UBC EnvCom is the Lead Partner, responsible for the overall management and coordination of the project.

John Nurminen Foundation

John Nurminen Foundation has two lines of operation: cultural activities focusing on maritime history, and the Clean Baltic Sea projects related to eutrophication and oil tanker safety. The Foundation's Clean Sea projects aim at significant reductions in nutrient load by implementing cost-effective investments. In PURE John Nurminen Foundation coordinates the technical studies and investments for enhanced phosphorus removal and activities related to sustainable sludge handling.

Baltic Marine Environment Protection Commission HELCOM

The Helsinki Commission (HELCOM) works to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between all the nine coastal countries surrounding the Baltic Sea. HELCOM is the governing body of the "Convention on the Protection of the Marine Environment of the Baltic Sea Area", or the Helsinki Convention. HELCOM Secretariat is responsible for PURE external communication and information dissemination.

Riga Water Ltd, SIA Rīgas ūdens (LV)

Riga Water Ltd is providing water supply, collection of waste water and waste water treatment for the city of Riga and agglomeration. The waste water treatment plant Daugavgriva's design capacity is 1 000 000 population equivalents and the purified waste water is discharged directly to the Baltic Sea, to the Gulf of Riga. In PURE Riga Water invests in equipment for chemical phosphorus removal and better sludge management. Implementing the HELCOM recommendation in Riga reduces the annual discharge of phosphorus to the Baltic Sea by over 100 tonnes compared to the year 2008.

Brest Municipal Unitary Water and Wastewater Enterprise, Brest Vodokanal (BY)

The City of Brest with over 300 000 inhabitants is situated in the border of Belarus and Poland. The waste waters from Brest are discharged to river Bug and flow through Poland to the Baltic Sea. Brestvodokanal has a significant role in improving the state of the Baltic Sea, as reaching the HELCOM recommendation in Brest waste water treatment plant reduces hundreds of tonnes of phosphorus load to the Sea. In PURE Brestvodokanal invests in chemical phosphorus removal equipment.

Jurmala Water, PIU Jūrmalas ūdens (LV)

Jurmala Water's Sloka waste water treatment plant is situated on the bank of the Lielupe river discharging to the Baltic Sea. Currently the waste water treatment plant treats the waste waters of approximately 30 000 inhabitants. In PURE Jurmala implements investments that improve the controllability of the biological waste water treatment process, especially the balance of nitrogen and phosphorus removal.

Water and Sewage Company of Szczecin, Zakład Wodociągów i Kanalizacji Sp z o.o. w Szczecinie ZWiK (PL)

Located on the river Odra, the port city of Szczecin plays an important role in the nutrient load to the Baltic Sea. During the past years the city has carried out large investments with the financial support of the EU structural funds to modernize its waste water treatment facilities. In PURE the waste water treatment plants "Pomorzany" (418 000 population equivalents) and "Zdroje" (177 000 p.e.) were audited and solutions for improved operation of the waste water treatment plants presented.

Sewage Management Facilities Lübeck, Entsorgungsbetriebe Lübeck (DE)

In Sewage Management Facilities Lübeck the HELCOM recommendation in phosphorus removal is achieved; the current level of phosphorus in outgoing waste waters is below 0,2 mg/l with an elimination rate of 99,0 % (400 000 population equivalents). In PURE Lübeck shares its good practices with the other participating waste water treatment plants and has a key role in sludge management activities of PURE.

Järve Biopuhastus OÜ (EE)

The regional waste water treatment plant Järve Biopuhastus treats waste waters of approximately 200 000 population equivalents and is owned by the municipalities Jõhvi, Kiviõli, Kohtla-Järve and Püssi. The purified waste waters are discharged to the Baltic Sea, Gulf of Finland. In PURE Kohtla-Järve waste water treatment plant was audited and solutions for improved operation of the waste water treatment plant presented.

City of Gdańsk, Urzad Miejski w Gdansku (PL)

City of Gdansk, a city of 455 000 inhabitants, is the sole shareholder of Gdansk Water and Sewage company GIWK who is the owner of the water and sewage infrastructure in Gdansk. In recent years, the Gdansk water and sewage infrastructure has gone through major renovations. In PURE Gdansk Wschód waste water treatment plant was audited and solutions for improved operation of the waste water treatment plant presented. The City of Gdansk hosts the project final conference.

Mariehamn Town, Mariehamns stad (FI)

UBC member city Mariehamn has a well-functioning waste water treatment plant of 30 000 population equivalents and Mariehamn's Environmental department is well advanced in developing its environmental monitoring system. In PURE Mariehamn Town is the responsible partner for developing the database of municipal nutrient loads around the Baltic Sea region.

Figure 1-3: PURE partner cities and capitals of the Baltic Sea countries.

2. INTRODUCTION

Photo: Shutterstock.com/Skyfish.

2.1 SEWAGE SLUDGE – PROBLEM OR POSSIBILITY

Efficient municipal waste water treatment produces vast amounts of sludge. For example, in the countries located wholly or partly on the Baltic Sea watershed the amount of sewage sludge generated is about 3.5 million tonnes of dry solids annually – this is expected to increase to almost four million tonnes by 2020. Sludge management is an integral part of any modern municipal waste water treatment plant: it is important not to lose the nutrients in the sludge, to make use of its material and energy, and to dispose of it efficiently and sustainably.

During recent years, much effort has been put to efficient nutrient removal from the municipal waste waters in the Baltic Sea region. The aim is to reduce the eutrophication burden to the fragile Baltic Sea by fulfilling the relevant requirements: the newer EU member states on the eastern and southern shores of the Baltic Sea have started to implement the Urban Wastewater Directive (see chapter 12 for legislation) and also to strive for the stricter HELCOM recommendations for nutrient removal. Also, in the non-EU countries of the region, actions have been taken – and are still on-going – to improve the level of waste water treatment.

The two main sludge fractions are primary and excess secondary sludge. If phosphorus is removed from the sewage by chemical precipitation, the amount of the sludge increases by the amount of chemicals used for the precipitation. The nutrients removed from waste water are contained in the sludge, which must be handled so that the nutrients are not released back to the watercourses, while the material and energy content of the sludge can be utilised. The large amounts of sewage sludge generated in waste water treatment plants provide numerous opportunities for beneficial use; for example, in power generation, soil improvement and even nutrient recycling. The possibilities of use are dependent on the quality and amount of the sludge in question, the processes used in a particular treatment plant, and the national legislation and policies.

Many – even modern – waste water treatment plants have some difficulties in their sludge disposal. Problems include the lack of machinery or chemicals to dewater or thicken the sludge and the reduced possibility to use metal-polluted sludge on agricultural land, for example. The sludge handling strategy of an individual waste water treatment plant is shaped, for example, according to: its location, transportation costs; the quality of incoming waters; the used nutrient removal technology; legal restrictions concerning sludge disposal; the availability and price of conditioning agents; and the possibilities to outsource the treated sludge products. The flexibility of any sludge management system allows the adaptation to the possible changes in national energy, waste or nutrient regulations, and market-based policy instruments such as feed-in tariffs or tax regulations. Regular upgrading of the system is needed to keep pace with the changing circumstances.

Figure 2-1. Photo: Shutterstock.com/Enieni.

An accurate and unbiased assessment of the risks connected to the use of sewage sludge is needed. The question is how to deal with various chemical substances present in municipal sewage sludge originating from households and how to recycle the nutrients. The issue of hazardous chemicals of the sludge is currently under debate and regulatory issues are also open with the EU Sewage Sludge Directive currently being revised.

There are international political dimensions to the sludge handling issue, not only in differing legislation, energy strategies and sludge handling costs, but also because the world's mineral resources of phosphorus are depleting. The question on nutrient recycling is emerging: according to some estimates, phosphorus resources may only be sufficient for the next 50 years. These resources are located mostly in northern Africa, China and the USA. Even though there have been some optimistic estimations on the global reserves, the dependency on a single country, Morocco, is expected to grow over the century. Thus, EU food security has to rely on imported phosphorus (Schröder et al., 2011).

Municipal sewage sludge contains large amounts of precious phosphorus; however, the possibilities for recycling should be taken into account already when planning sludge management alternatives. Moreover, some sewage treatment methods do not allow the phosphorus to exist in an easily usable form in the sludge.

2.2 BASICS OF SLUDGE TREATMENT IN MUNICIPAL WASTE WATER TREATMENT PLANTS

Sewage sludge is a product of municipal waste water treatment; however, sludge treatment issues are often neglected in comparison with water-related parameters such as the outgoing load and the degree of removal of different waste water compounds. Sludge is a potential threat for the environment; for example, foaming sludge can be lost from the treatment process or sewage sludge may be even deliberately disposed of into watercourses.

Decades ago, when sewage treatment was only taking its first steps, sewage sludge was dumped into international waters. In some countries, this is still a practice. Besides sewage sludge, waste water treatment has such side products as solids from the screening and sand out of the mechanical treatment. Solids can be dewatered and burnt in an incineration plant, for example, while sand has to be washed and can be used in landfills as structure material.

The practical and technical challenges of sludge handling are the following:

- stabilising – sludge is not inert and can have an unpleasant odour;
- reducing the water content and sludge volume to the minimum;
- utilising the energy potential when economically possible;
- reducing the amount of harmful micro-organisms if people, animals or plants are in contact with the sludge; and
- recovering phosphorus for agriculture.

Figure 2-2. Photo: Shutterstock.com/Kekyalyaynen.

Although there are many different sludge handling practices in the Baltic Sea Region countries, the proven standard practices are more or less applied in all of them. There are differences between countries with regards to the abundance and coverage of different sludge handling methods, some of which are obviously mutually exclusive such as using centrifuge or a belt filter press in sludge dewatering. Sludge drying with incineration is widely applied only in Germany and to a lesser extent in Poland and Sweden. To date, cost effective phosphorus recovery methods are not available in the Baltic Sea Region; however, there are many research projects and pilot plants, especially in Germany, because of the incineration practices there.

In the coming years, the amount of sewage sludge generated in the Baltic Sea region is estimated to increase, mainly because enhanced waste water treatment methods are taken in use in countries like Poland, Latvia, Belarus and Russia (Table 2-1).

There are different types of sludge with different physical and biological properties. Typical sewage sludge is made up of primary and secondary sludges (Figure 2-3).

Primary sludge is taken out from the primary sedimentation tank. Its amount depends on the retention time and on the volume of the tank. Primary sludge is rich in organic compounds and optimal for anaerobic treatment. Sometimes treatment plants have only a small or no primary sedimentation tank to increase the substrate for the denitrifying part of the biological treatment process. Primary sludge has in average a dry solids (DS) content of about 4 %. The organic fraction is on average 67 %. (ATV-DVWK-M 368E, 2003)

Secondary sludge is taken out from the clarifier (secondary sedimentation tank). In the aeration basin, the microbial content is high. The retention time of the bacteria in the aeration is between 10 and 20 days, depending on temperature, population equivalent of the waste water treatment plant and the nitrogen removal technique (ATV-DVWK-A 131E, 2000). Especially for nitrogen removal purposes, the bacteria need retention time for growing and thus the sludge must be circulated (**return activated sludge**). Part of the secondary sludge is not needed anymore (**excess sludge i.e. surplus sludge or waste activated sludge**). The amount depends on the sludge retention time, the use of substrates like methanol, phosphorus precipitation, biological phosphorus removal and, of course, a proceeding treatment such as biological filtration. The chemical precipitation of phosphorus increases the inorganic fraction of the sludge.

Table 2-1: Total sludge volumes in tonnes of dry solids per year (tDS/a) of different countries of the Baltic Sea Region reported to the EU Commission and estimated to develop by respective Member States (Milieu, WRc and RPA 2008).

Country	2005 / 2006	2010	2020
	(tDS/a)	(tDS/a)	(tDS/a)
Belarus*	50 000	50 000	70 000
Denmark	140 021	140 000	140 000
Estonia	n.d.	33 000	33 000
Finland	147 000	155 000	155 000
Germany	2 059 351	2 000 000	2 000 000
Latvia	23 942	25 000	50 000
Lithuania	71 252	80 000	80 000
Poland	523 674	520 000	950 000
Russia*	180 000	180 000	200 000
Sweden	210 000	250 000	250 000
Total	3 405 240	3 433 000	3 928 000

*Non-EU countries; and hence no data available in Milieu et al., 2008 report, order of magnitude estimated by Pöyry Finland Oy for PURE, based on population connected to municipal systems in the Baltic Sea Region.

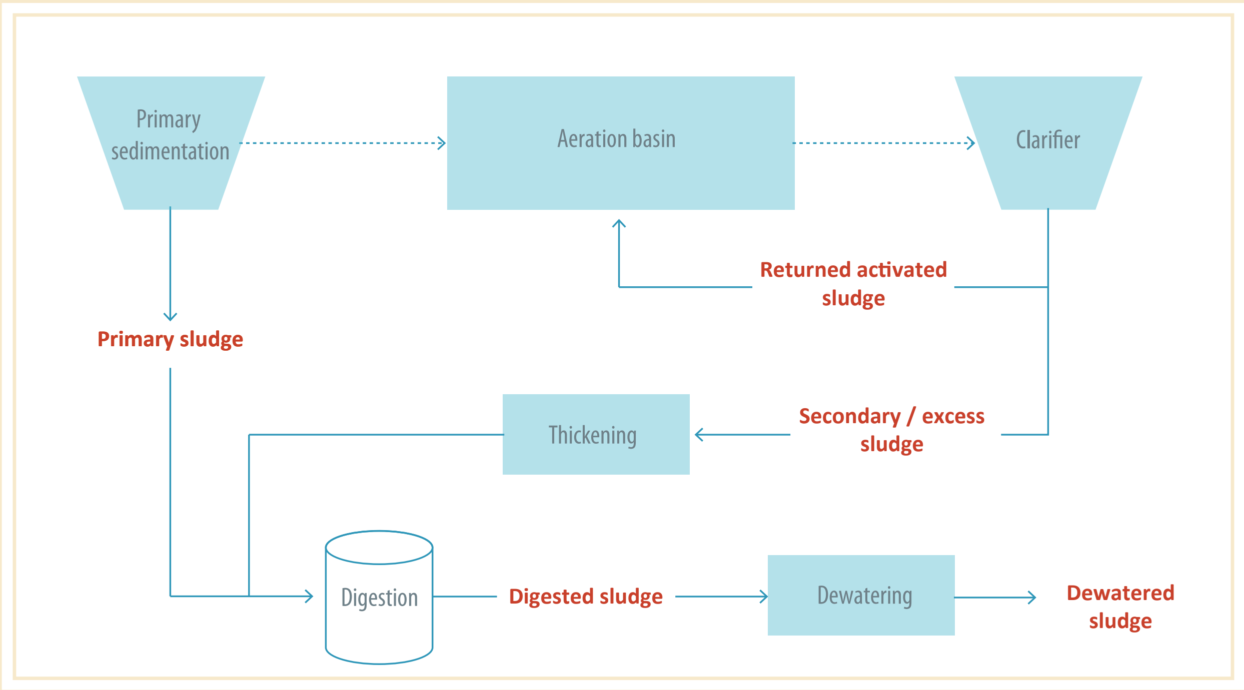


Figure 2-3: Different types of sludges generated in an urban waste water treatment plant process.

Compared with primary sludge, excess sludge has only a DS content of 0.5–1.0 %. The organic content depends on the amount of used precipitant and is between 70 and 80 % on average. Due to the bacteria, which have grown in the aeration tank, the bacterial content is much higher. Usually, excess sludge has worse thickening characteristics than primary sludge. (ATV-DVWK-M 368E, 2003). This reveals that the excess sludge must be thickened additionally. Also, excess sludge is usually thickened mechanically (section 3.3) or in gravity thickeners. Primary sludge is often thickened in gravity thickeners (section 3.3). The term **raw sludge** can be used to refer either to primary sludge (sludge that is removed from the system before the biological treatment step); to primary/excess sludge; or a mixture of them prior to stabilisation.

Sludge that has been stabilised anaerobically (chapter 4) is called **digested sludge**. Anaerobic digestion is the main stabilisation method in municipal sewage sludge treatment. The main benefits are the reduction of organic matter and the production of methane gas, which can be used to achieve the required treatment temperature (often 35–40 °C) and the production of electricity. After digestion, the sludge has a much lower volatile solids content and the odour has changed.

A maximum volume reduction is attempted after digestion (if applied) to reduce transport and disposal costs. Dewatering (chapter 5) reduces the water content from over 95 % to 60–80 %. The **dewatered sludge** is not pumpable anymore. It can be used in agriculture (after possible treatment improving the hygienic quality of the sludge, chapter 6) or dried (chapter 7) and burnt (chapter 8) in an incineration plant. Also, disposal to landfill is possible in certain countries. The applied disposal method (chapter 9) mostly depends on the national regulatory framework (chapter 12).

Sewage sludge treatment is more than only thickening, digestion, dewatering and disposal. It has consequences for the whole treatment plant:

- With sludge-originated biogas, it is possible to increase energy production (electrical and thermal) to over 100% of the power needed in the plant. Energy production and energy efficiency are thus very important issues. It is also possible to increase biogas production with certain pre-treatment methods.
- The retention time in primary sedimentation has a direct positive effect on the biogas production. On the other hand, a higher retention time decreases the BOD load in the biological treatment; this decreases the denitrification capacity and may require an additional carbon source. Other possible effects are better dewaterability and lower disposal costs.
- In digestion, nitrogen is reduced to ammonia, which is in high concentration in the reject water that is separated from the sludge in dewatering.

Better digestion causes a higher reject water load. If the nitrogen removal capacity of the waste water treatment plant is too low, additional reject water treatment methods can be applied (chapter 10).

- Biological phosphorus removal reduces the dewaterabilty up to 10 % (Kopp, 2010). Some plants have problems to operate a stable biological phosphorus removal or have other operational problems (e.g. bulking sludge). Chemical phosphorus removal, in turn, increases the amount of sludge.

In this publication, the waste water treatment plants are divided into **small (< 10 000** population equivalents, **PE**), **medium-size (10 000 –100 000 PE)** and **large (> 100 000 PE)** plants.

2.3 TYPICAL SLUDGE HANDLING TECHNOLOGY COMBINATIONS

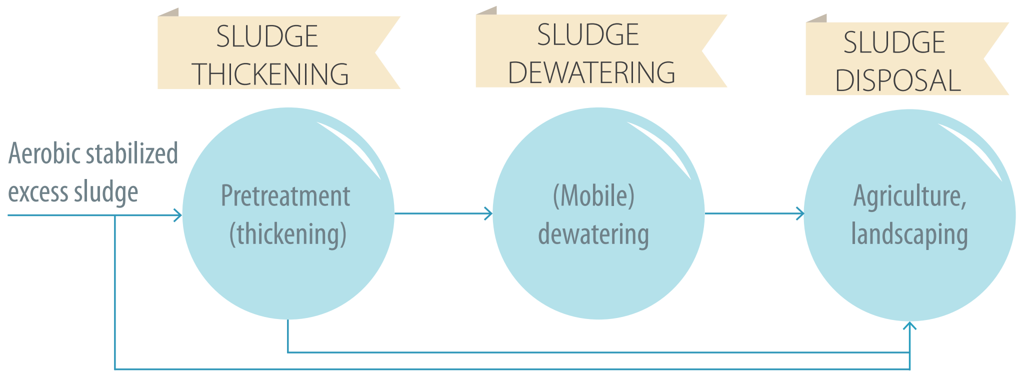


Figure 2-4: Typical sludge handling for small and medium-size waste water treatment plants with aerobic stabilisation.

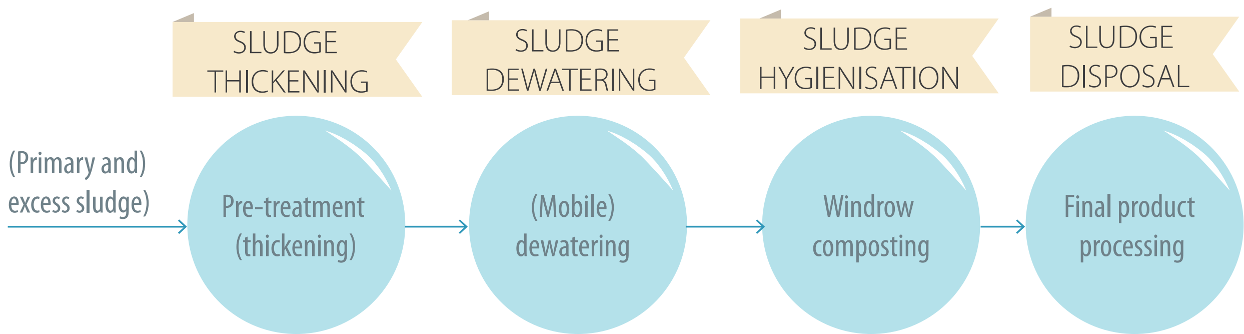


Figure 2-5 Typical sludge handling for small and medium-size waste water treatment plants with composting.

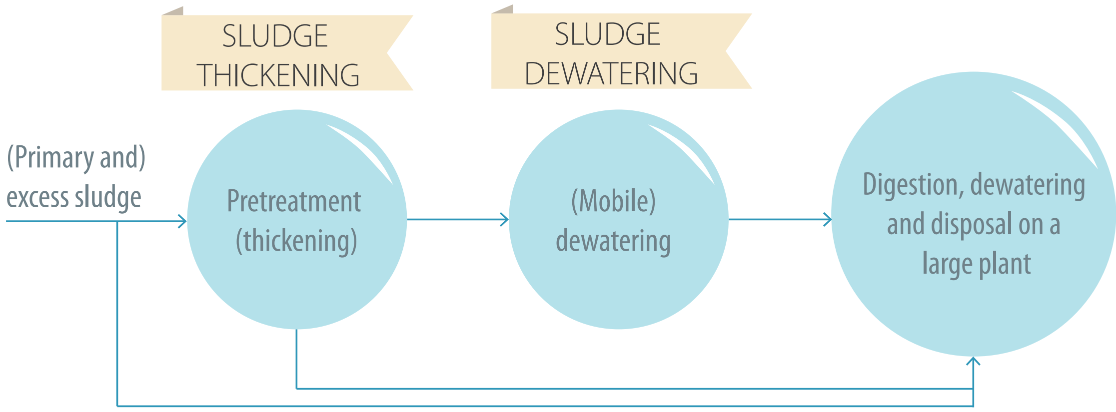


Figure 2-6: Typical sludge handling for medium-size waste water treatment plants.

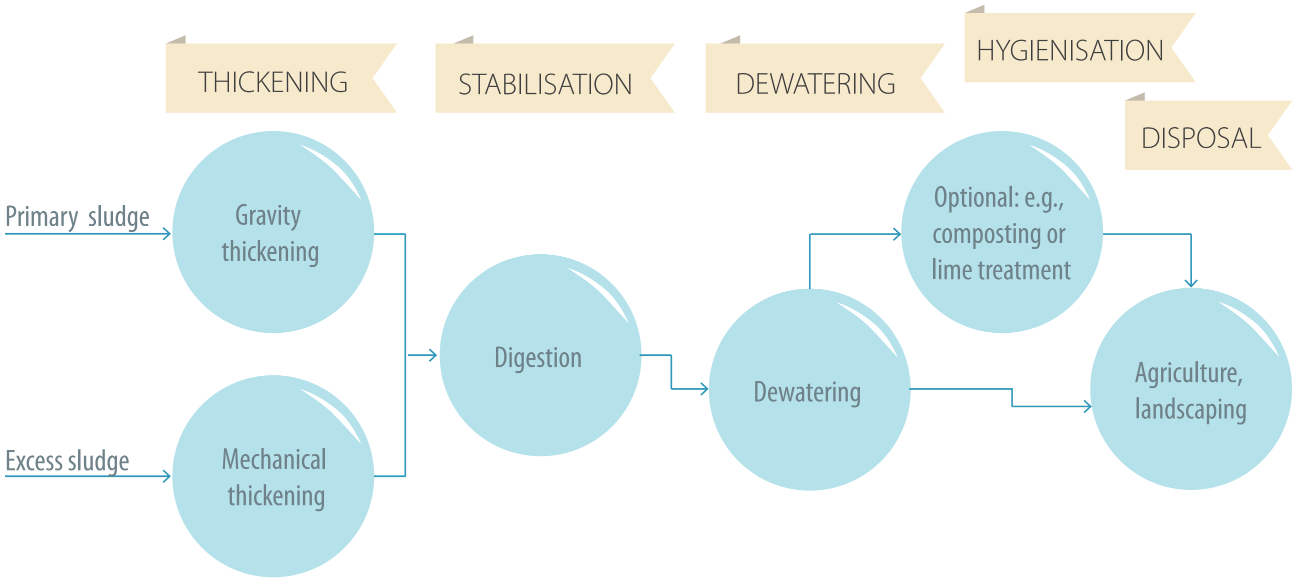


Figure 2-7: Typical sludge handling for medium-size and large waste water treatment plants.

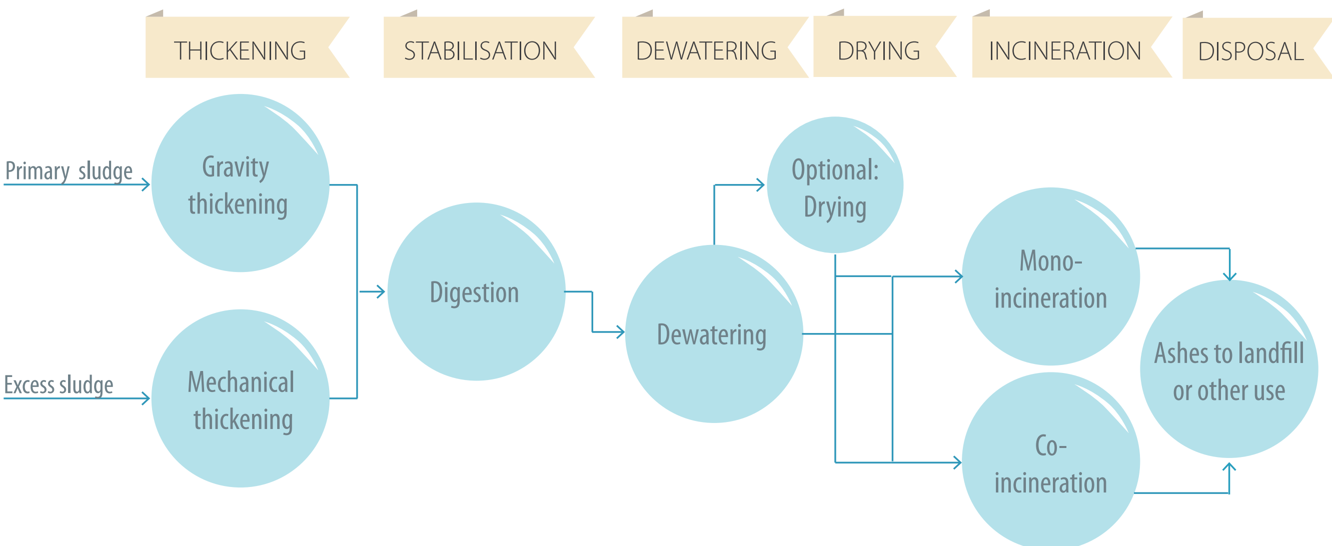


Figure 2-8: Typical sludge handling for large waste water treatment plants.

2.4 EXAMPLE: PURE partner sludge handling solutions – GDANSK, Gdanska Infrastuktura Wodociagowo-Kanalizacyjna Sp. z o. o., Wschód

The waste water treatment plant in Gdansk, Poland, is the largest waste water treatment plant participating in the PURE project. It is equipped with biological phosphorus and nitrogen removal (MUCT process) and has a possibility for chemical phosphorus precipitation. The plant treats the waste water of a total of 781 000 population equivalents. Some 18 374 tonnes of sewage sludge (dry solids, DS) are treated annually.

Due to the large volume in primary sedimentation with a retention time of 3.7 h, a significant amount of primary sludge is generated. Primary sludge is thickened in a gravity thickener to a DS content of 4.8 % and then sent to the digester. The excess sludge is first thickened in a gravity thickener and then mechanically treated in a screw press to a DS content of 6 %. The polymer consumption is about 3.4 g/kg DS (grams per kilogram of dry solids).

The digestion is supported by ultrasonic disintegration to increase gas production and reduce the amount of sludge. The mesophilic digestion has a retention time of 28 days and a temperature of 37 °C. The content of the solids in the digester is around 3.1 %.

Digested sludge is dewatered using centrifuges. A dry matter content of 19.7 % with a polymer consumption of 11.4 g/kg DS are the characteristics of the dewatering. Subsequent drying, with energy from fuel oil, ensures a dry solid content of 31.4 %. The process of contact drying is used for this purpose.

At the waste water treatment plant in Gdansk, biogas is produced and used in high-efficiency CHP (combined heat and power plant, 40.5 % electrical efficiency) to gain electricity and heat. The amount of electricity is sufficient for the CHP and sludge incineration plant, so that 100 % of the electricity needed can be produced in the CHP. Surplus amounts are sold to an industrial power network. The heat gained is used to cover the treatment plant's technological needs. Biogas can also be stored for up to 10 h, which enables good emergency preparedness.

Until now, part of the sludge has been diverted for composting and used for landfill remediation. After the sludge incineration plant is ready for use, all the sludge will be burned. Agricultural disposal is not practised due to limited demand for the product in the region and the relatively high heavy metal concentrations. Landfilling of sludge will have more stringent regulations in Poland from 2013 (corresponding to EU directives).

Future plans of sewage sludge management include reducing the stored amount of sewage sludge and the total abolishment of sewage sludge storage by 2015. The amount of sludge disposed of by thermal methods will be increased.

Figure 2-9: Wschód waste water treatment plant in Gdansk. Photo: GIWK.

2.5 EXAMPLE: PURE partner sludge handling solutions – BREST, Municipal Unitary Production Enterprise Brestvodokanal

The city of Brest, Belarus has over 300 000 inhabitants. Brest waste water treatment plant has conventional activated sludge process for BOD removal. In PURE project, investments in chemical precipitation of phosphorus are carried out. A reconstruction of the plant with loans from international financing institutions is also being prepared planned at Brest waste water treatment plant. From 2010, all sludge from Brest waste water treatment plant is directed to Brest waste processing plant, owned and operated by an external company and located next to the waste water treatment plant. Brest Vodokanal has agreed with the processing plant that both primary and excess sludge are handled by the processing plant against a fee, paid by the Vodokanal. The processing plant mixes municipal solid waste with the sludge and the processed sludge is disposed to a landfill of the processing plant. The reject waters from the plant are directed to the beginning of the waste water treatment process after pre-treatment at the waste processing plant. The operational data of the plant is not publicly available.

Formerly the sludge from the Brest waste water treatment plant was stored in sludge lagoons located alongside the river Bug. The total volume of the lagoons is 100 000 m^3. In 2002, two belt filter presses to decrease the sludge volume were delivered to the plant with Danish financing and installed to the building of mechanical treatment. Currently there is on on-going Polish-Belarusian co-operation project for emptying the sludge lagoons and for preventing the leakages of the sludge from the lagoons to the river. Within this project, one mobile and one stationary belt filter press manufactured in Denmark have been delivered to the plant. The mobile dewatering unit is located next to the sludge lagoons and the stationary one in the building for mechanical treatment. The funding comes from the Polish National Fund for Environmental Protection and Water Management according to an agreement between the Fund, Brest city authorities and Brest Vodokanal.

The first of the sludge lagoons have been emptied wholly and at the moment the other one is being emptied. The dewatered sludge is directed to Brest Vodokanal's landfill, about 30 km away from river Bug. The old sludge lagoons are going to be cultivated to a green zone.

Figure 2- 10. Brest Vodokanal.
Photo: Pekka Sarkkinen.

3. SLUDGE THICKENING

Photo: Samuli Korpinen, HELCOM.

3.1 INTRODUCTION

The sludge that comes out of waste water treatment has a water content of between 97 % and 99.5 %. In sludge thickening, the dry solids (DS) content of sludge is increased by reducing the water content with low energy input. Sludge thickening can be applied both as a pre-treatment for digestion as well as a pre-treatment for dewatering in waste water treatment plants that operate without digestion (see flowcharts in section 2.3).

Good to know:
As some dewatering devices are also able to dewater sludge with very high water content, separate thickening is not always necessary. Consultations with the manufacturers are recommended.

With gravity and mechanical thickening, it is possible to treat primary sludge, excess sludge or a mixture of both. Thickening excess sludge has a high priority because after secondary sedimentation, the DS content of the sludge is about 0.5–1.0 %, while primary sludge from primary sedimentation tanks can have a DS content of up to 4.0 %. Small and medium-size waste water treatment plants often have only a small primary sedimentation tank or no primary sedimentation at all. The major amount of sludge at these plants is excess sludge and the primary and secondary sludges are treated together, for example in gravity thickening. As this mixture of primary and excess sludge has better settlement characteristics than excess sludge alone, gravity thickening is more efficient. Of course, each treatment plant has its own solution for sludge thickening; moreover, a large waste water treatment plant may have only a small primary sedimentation tank and thus combined thickening may be more economical. At some small waste water treatment plants there is no thickener at all.

In sludge thickening – like in sludge dewatering (see chapter 5) – inorganic or organic flocculant aid chemicals (usually polymers) are used. With all thickening and dewatering methods they are, however, not absolutely necessary. The flocculant aids need specific mixing, storage and feeding conditions, which can be obtained from their manufacturer or the manufacturer of the thickener. Optimising polymer dosing and mixing helps to improve the thickening result. The mixtures of sludges in different waste water treatment plants have their own characteristics and therefore testing in laboratory and in full scale is highly recommended in order to find the optimal result and cost.

The achieved DS content, energy consumption and chemical consumption vary with the type of sludge – different sources give different information on these parameters. In this publication, a synthesis of numerical data of different information sources (PURE Pöyry report, Burton et al., 2003 and DWA M- 381E, 2003) concerning thickening is presented, including data from PURE project partners. The results of PURE partner waste water treatment plants with the thickening technique they apply are shown in the end of the section.

Figure 3-1. Photo: Shutterstock.com/John Kasawa.

3.2 GRAVITY THICKENING

Operating principles, performance results and space requirements

Gravity thickening is the easiest way to reduce the water content of sewage sludge with low energy consumption. Sludge is pumped directly to a circular tank equipped with a slowly rotating rake mechanism, which breaks the junction between the sludge particles and therefore increases settling and compaction.

The incoming sludge flow is directed to the central cone of the tank. The most important criteria in thickener design and operation is the mass loading per square meter and sufficient volume providing enough detention time for good settling. Settled sludge is collected at the bottom of the tank and pumped out from the bottom outlet pipe to the next treatment step, which could be a digester, dewatering equipment or a secondary (mechanical) thickener (Figure 3-3). Even sludge that is not thickened and stabilised can sometimes be directly used in agriculture, for example sludge from small waste water treatment plants in Germany.

It is not recommended to use flocculant aids for the thickening of primary sludge. For thickening a mixture of sludges or excess sludge only, flocculant aids can be used to make the thickening result better (Table 3-1).

With gravity thickening, the total sludge volume can be reduced by even 90 % from the original volume; this method consumes very little energy.

Gravity thickening normally requires its own basin – usually circular and made from concrete. A typical basin diameter is 8–20 m. Gravity thickener can be placed outdoors, although in densely populated areas and in the vicinity of residential or office buildings the basin may require to be covered with a light roof and ventilation in order to avoid emissions of malodorous gases (containing hydrogen sulphide, H_2S).

Good to know:

Another target of gravity thickening is the significant hydraulic buffering capacity (up to 3 days) between the waste water stream and the sludge handling process. Often, gravity thickeners are designed as buffer tanks, especially when part of the plant, such as dewatering, is not in operation continuously. In these cases, gravity thickeners are often preferred to mechanical thickening.

Thickening can sometimes be carried out inside the primary or secondary clarifier. In this case, the sludge pit is a deep zone (>4 m) at the beginning of a vertical primary clarifier (e.g. in Viikinmäki waste water treatment plant in Helsinki, Finland) or in the middle part of a circular secondary clarifier, which is enlarged to a bigger sludge bunker where gravity thickening takes place (as in a few industrial waste water treatment plants). The total reached sludge DS content is smaller and the risk of anaerobic conditions is higher compared to conventional gravity thickening. The suitability of this solution depends on the conditions in the waste water treatment plant.

Suitability for different types of sludges, and different types and sizes of operation

All types of sludges can be thickened by gravity. Adding flocculation aid might be needed depending on the settling properties of sludge. Also, digested

Table 3-1: Results as dry solids (DS) contents of gravity thickening with or without flocculant aids (DWA-M 381E, 2007), (Burton et al., 2003).

	Without flocculant aids	With flocculant aids (polymers)
Primary sludge	5–10 % DS	-
Mixture of primary and excess sludge	4–6 % DS	5–8 % DS
Excess sludge	2–3 % DS	3–4 % DS

Figure 3-2: Gravity thickener in Lübeck, Germany.
Photo: Entsorgungsbetriebe Lübeck.

sludge can be thickened, but it is often dewatered directly. This method is suitable for medium-size and large waste water treatment plants. Sometimes there is no thickening; the sludge is pumped directly to sludge dewatering – a practice that is taken into account in the design of the sludge dewatering capacity.

Operation, maintenance, environmental and safety aspects

Gravity thickening is continuously in operation as a thickener and buffer tank. It normally requires cleaning or maintenance work every 1–2 months; however, in case of sludge bulking, the thickener should be cleaned more often (depending on the frequency of bulking problems which should also be solved for other reasons). In some plants, cleaning is done only when problems are detected.

Good to know:
If the volume of the primary sedimentation is very large, it is possible to feed excess sludge in the primary sedimentation to achieve combined sedimentation. In this way, it is possible to reach DS contents of 3 %–3.5 % with very low energy and chemical consumption. This is a good solution if the digestion capacity is available and the volume of primary sedimentation is very high. It can also be a solution if the use of polymers is restricted.

Environmental aspects are associated with potential air emissions of malodorous gases. These emissions can be reduced by chemical treatment with calcium hydroxide (applicable at small or medium-size plants) or by covering the basin and arranging ventilation (applicable at large plants). When the waste water treatment is located in the vicinity of residential areas or other densely populated areas, an odour control of the thickener may also be required by the regulatory authorities.

Costs, unit consumptions and manpower

Investment costs for gravity thickening mainly depend on the volume of the basin and the ground conditions. Odour emissions increase the costs. The overall investment costs are high (typical range from EUR 150 000 to EUR 400 000), but the operational costs are low. The technical lifetime of the concrete basin is over 40 years, the main equipment 20–25 years and auxiliary equipment about 10–15 years. The

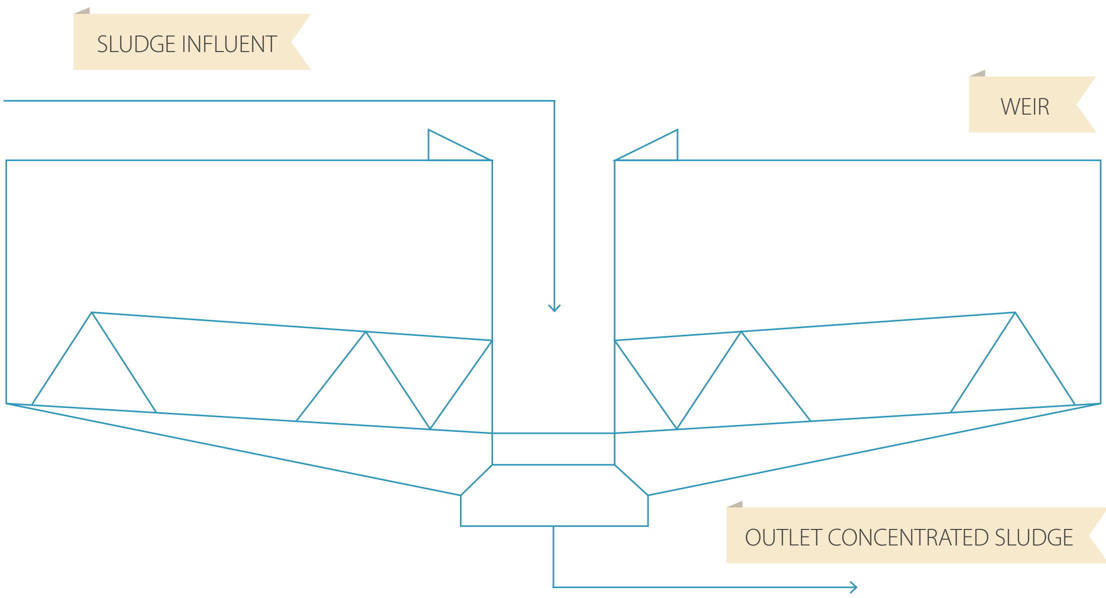


Figure 3-3: Schematic diagram of a gravity thickener.

electrical power consumption is low (2–6 kWh/t DS). If flocculant aid is used, the chemical consumption of this unit is about 0.5–3 kg flocculant aid per tonne of DS. This unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

Use in the Baltic Sea Region

Gravity thickeners are in use in nearly all large and medium-size waste water treatment plants in the Baltic Sea Region, for example in Tallinn, Tartu and Pärnu in Estonia; Espoo, Turku and Oulu in Finland; Stockholm in Sweden; Riga in Latvia; Vilnius and Kaunas in Lithuania; Warsaw and Gdansk in Poland; St. Petersburg in Russia; Copenhagen in Denmark and also Berlin and Hamburg in Germany.

The gravity thickener can be either replaced (e.g. in Lahti, Finland or Kohtla-Järve, Estonia) or complemented with other thickening equipment, which is usually needed if there is also anaerobic treatment of sludge at the plant. Sometimes, gravity thickening (or any other thickening) is not used in medium-size or small treatment plants in Estonia, Latvia, Poland and Germany, for example. In these cases, the type and capacity of the sludge dewatering equipment is designed to take into account that there is no preceding thickening stage.

3.3 MECHANICAL THICKENING

Mechanical thickening is usually used for thickening excess sludge. It is also possible to thicken primary sludge or a mixture of primary and excess sludges mechanically. The mixture of sludges is often thickened mechanically at plants with a small primary sedimentation unit or when the sludge is not treated in the digestion process.

Mechanical thickening needs flocculant aid and electrical energy. The flocculant aid is fed in a flocculation reactor with a stirrer to ensure good mixing and stabile flocks. The mechanical thickening methods can be operated continuously (24/7). It is also possible (especially for medium-size plants) to operate in shifts such as 8/5 or 16/5. In these cases, a buffer tank (see section 3.2) is required.

Mechanical thickening is typical for large and medium-size waste water treatment plants and as pre-treatment for direct dewatering without digestion. The cost of the mechanical thickening equipment ranges from EUR 70 000 to EUR 150 000 with a technical lifetime of 15–20 years. Typical cleaning procedures must be carried out approximately every two weeks. There are no particular environmental or safety issues with the different mechanical thickening methods.

Figure 3-4. Gravity thickeners in Zdroje treament plant, Szczecin, Poland. Photo: ZWiK Szczecin.

The following sections describe some specific mechanical thickening methods. There are also other methods, like disk thickeners, which can be used but are not presented in this publication.

3.3.1. Screw thickening

Operating principles, performance results and space requirements

A screw thickener consists of an inclined wedge section basket. A screw, slowly rotating with variable speed, conveys the sludge gently upward through the inclined basket. Water drains through the basket. The degree of thickening is regulated with an adjustable outlet plate in the sludge discharge and variable screw speed. The wedge wire basket is cleaned during the operation by means of an automatic washing system.

Screw thickening is a suitable procedure for sludge thickening from contents of 0.5–1 % DS to final contents of 4–7 % DS in normal municipal applications. The total sludge volume can be reduced by 90 % from the original volume with low energy and water consumption for washing.

Screw thickeners are normally manufactured of stainless steel and their capacity varies from 20 m^3/h to 100 m^3/h. The physical structure of the equipment is closed to minimise the odour impact. Space requirements depend on the capacity; typical ranges are: width 2–4 m; length 5–10 m; and height 3–6 m, including the space needed for maintenance. This equipment always requires indoor installation.

Costs and consumptions

Installed power is approximately 4–10 kW; the electrical power consumption of this unit process is marginal compared to the overall consumption of waste water treatment (some 3–7 kWh/t DS). It depends on the actual operating time of the equipment. Chemical consumption is around 2–6 kg flocculant aid per tonne of DS. This unit process does not require any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

3.3.2 Drum thickening

Operating principles, performance results and space requirements

A rotary drum thickening system consists of a sludge flocculation unit including the flocculant aid feeding and rotating cylindrical screens. Flocculated sludge is fed to the rotating screen drums, which separate the sludge from the water. The thickened sludge rolls on the end of the drums and the separated water decants through the screens.

The technical features are similar to screw thickeners and the throughputs range from 10 m^3/h to over 70 m^3/h depending on the feed and the required output DS content. The total sludge volume can be reduced by 90 % from the original volume. The sludge can be thickened to 5–7 % DS with drum thickening.

The drum thickener is manufactured from stainless steel and is fully enclosed to minimise odours and environmental impact. However, inspection doors and removable side panels are provided to allow easy access and maintenance. The main advantages of the rotary drum thickeners are low maintenance costs, low energy and water use, and small space requirements (area and volume). Space requirements depend on the capacity; typical ranges are: width 2–3 m; length 7–15 m; and height 3 m, including space needed for maintenance. This equipment always requires indoor installation.

Costs and consumptions

The electrical power consumption is comparable with the screw thickener (3–7 kWh/t DS). The installed

Figure 3-5: Rotary drum thickeners in Jurmala, Latvia and Szczecin, Poland. Photos: PIU Jurmalas Udens and ZWiK Szczecin.

power is 4–10 kW. Chemical consumption is maximum 2–6 kg flocculant aid per tonne of DS. This unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

3.3.3 Belt thickening

Operating principles, performance results and space requirements

Belt thickener or gravity belt thickener was developed from the belt filter press for dewatering, which is described in section 5.3. The belt thickener consists of a gravity belt, which moves over rollers driven by a speed unit. After a flocculation unit, the sludge is fed continuously and evenly across the width of the belt. Water drains through the belt so that at the end of the belt the sludge reaches the targeted DS content. To support the water drainage, the belt is equipped with 'plow blades' which are evenly distributed. The belt is cleaned automatically with filtrate water.

The capacity is normally between 24 m^3/h and 180 m^3/h. The total sludge volume can be reduced by 90 % from the original volume. The achieved average DS contents are about 5–7 %. Space requirements depend on the capacity; it is comparable with a screw thickener.

The belt thickener is manufactured from stainless steel and should be fully enclosed to minimise odours and environmental impact. The cover is removable for easy access and maintenance. The main advantages of belt thickeners are low maintenance and energy costs, and small space requirements (area and volume).

Costs, unit consumptions and manpower

The energy consumption is low. The installed power varies, depending on the manufacturer, from 3–10 kW (c. 3–7 kWh/t DS). Chemical consumption is usually between 2–6 kg flocculant aid per tonne of DS. No additional manpower or special competences are needed for belt thickener operation.

Figure 3–6: Belt thickenersin Szczecin, Poland and Lübeck, Germany. Photos: ZWiK Szczecin and Entsorgungsbetriebe Lübeck.

3.3.4 Centrifuge thickening

Centrifuges are used for thickening and dewatering. Dewatering centrifuges are explained in detail in section 5.2. Dewatering and thickening centrifuges have some major differences in their design. Thickening centrifuges are designed to reduce water in an efficient way with lower energy input and lower chemical consumption; dewatering centrifuges, on the other hand, are designed to reduce a maximum amount of water.

Centrifuges are manufactured from stainless steel and are fully enclosed to minimise odours and environmental impact. The centrifuge rotates very fast to separate the liquid and solids. The capacity is between 5 m^3/h and 200 m^3/h. Thickening centrifuges can reach a DS content of about 5–7 %. Space requirements depend on the capacity; it is comparable with a drum thickener.

Costs, unit consumptions and manpower

The required chemical dosing with centrifuge thickening is low (1.0−1.5 g/kg DS); however, the energy consumption is much higher compared to the other mechanical thickening methods. Unlike the other three mechanical thickening methods, centrifuges can also operate without any flocculant aid. However, in this case the separation effect is much lower than with a flocculant.

3.4 EXAMPLE: PURE partner sludge handling solutions – RIGA, SIA Rigas Udens, Daugavgrīva waste water treatment plant

The waste water treatment plant in Riga is the largest plant in Latvia. It has a total capacity of some 1 000 000 population equivalents and a current production of about 6 857 tonnes of sewage sludge (dry solids, DS) which has to be disposed of annually. The treatment plant is equipped with a modern nitrogen removal (re-built in summer 2012) and phosphorus precipitation that is part-financed by the PURE Project.

Primary sludge is obtained in the primary sedimentation, which has a retention time of 2.5 hours. A DS content of 4 to 5 % can be achieved. The excess sludge is mechanically thickened by a centrifuge, which has a low polymer consumption (2–4 g/kg DS). The dry solid content of the excess sludge can be increased up to 5–7 % resulting in a total DS content of 3 º after the digester. The biological digestion takes place at a temperature of 37 °C for 14 to 20 days.

Figure 3-7: Daugavgriva waste water treatment plant in Riga. Photo: SIA Rigas Udens.

The biogas is stored in a 2 500 m^3 gas storage tank. Produced gas can be stored up to 5 hours and is useful for operating the combined heat and power plant (CHP). The CHP has a power of about 2 MW electrically and its maximum electrical efficiency is 38.9 %. The internal power supply is electrically at 45 % and thermally 55 %. The CHP operation is outsourced and run by a separate company.

Digested sludge is conditioned with polymers after digestion (8 g/kg DS) and dewatered with centrifuges. However, only a DS content of 22 % is achievable. All the sludge is destined to be disposed of for use in agriculture, the most common way for sludge disposal in Latvia. To date, there have been no problems with the limit values of pollutants.

Figure 3-8: Sludge transport at Daugavgriva waste water treatment plant. Photo: SIA Rigas Udens.

3.5 SUMMARY OF MAIN THICKENING METHODS

With gravity thickening, thickening can be achieved with low operational costs. Mechanical thickening has much higher operational costs but the reachable DS content is also higher. In addition to the investment costs of a mechanical thickener, buffer tanks are needed and thus it may be economical to only invest in a gravity thickener.

Especially for larger waste water treatment plants with digestion, continuously operating mechanical thickening is more suitable because higher DS contents can be achieved and digester can be fed with a higher DS content. This reduces the energy consumption for heating up the sludge in digestion. If the digester has a low detention time, thickening can be used to enhance digestion.

A comparison of the different mechanical thickening methods is presented in Table 3-2. The given values are typical values, mostly for excess sludge. The type of sludge affects the values. A comparison of PURE partner plants is presented in Table 3-3.

Clarified water from thickening is returned to the waste water treatment plant or treated together with dewatering reject water. Nutrient concentration in the clarified water of sludge thickening is usually low.

Good to know:
Sludge characteristics change in winter and summer, meaning that polymer consumption also increases or decreases. In the changing period from warm to cold or from cold to warm seasons, especially during wintertime, thickening, digestion and dewatering need to be monitored. Bulking sludge, in particular, may cause problems.

Figure 3-9. Photo: Shutterstock.com/Nostal6ie.

Table 3-2: Comparison between different thickeners. DS = dry solids.

Technology	Screw thickener	Drum thickener	Belt thickener	Centrifuge
DS content	4–7 %	5–7 %	5–7 %	5–7 %
Polymer consumption	2–6 g/kg DS	2–6 g/kg DS	2–6 g/kg DS	1–1.5 g/kg DS
Energy consumption	Low	Low	Low	High
Maintenance	Low	Low	Low	Low
Capacity and remarks	20–100 m^3/h	10–70 m^3/h	24–180 m^3/h	5–200 m^3/h, use without polymers possible
Examples in the Baltic Sea Region	Joensuu-Kuhasalo (FI), Lübeck Priwall (DE), Gdansk (PL)	Aarhus-Egå (DK), Szczecin-Zdroje (PL), Jurmala (LV)	Szczecin-Pomorzany, Wroclaw (PL), Lübeck-ZKW (DE), Kohtla-Järve (EE)	Riga (LV), Henriksdalen, Stockholm (SE)

Table 3-3: PURE partner comparison. DS = dry solids.

PURE partner	Method of thickening for excess sludge	Achieved DS	Flocculation aid consumption
Kohtla-Järve	Belt thickeners	6 %	4.0 g/kg DS
Riga	Centrifuge	5−7 %	2−4 g/kg DS
Jurmala	Drum thickener	4−7 %	3.5 g/kg DS
Gdansk	Screw thickener	6 %	3.4 g/kg DS
Szczecin Pomorzany	Belt thickener	6 %	3-5 g/kg DS
Szczecin Zdroje	Drum thickener	6.5 %	6.5 g/kg DS
Lübeck ZKW	Belt thickener	5−6 %	1.5 g/kg DS

4. STABILISATION

Mussels and barnackles from the Gulf of Finland. Photo: Essi Keskinen, Metsähaliltus.

4.1 PRINCIPLES OF ANAEROBIC DIGESTION

The aim of stabilisation is the reduction of biological and chemical reactions to a minimum. Anaerobic digestion is one of the oldest and still most commonly used processes for sludge stabilization. The first anaerobic digestion tanks were introduced over a hundred years ago in the United States. Concentrated organic and inorganic sludge matter is decomposed microbiologically in the absence of oxygen and converted to methane and inorganic end products. The main benefits from digestion are the stabilisation of sewage sludge, volume reduction and biogas production.

The anaerobic digestion process is operated either in the mesophilic (around 35–40 °C) or thermophilic (53–57 °C) temperature ranges. The main advantages of thermophilic treatment are higher sludge treatment capacity and a better sludge dewatering result with a higher hygienic quality of the treated sludge. The disadvantages are higher energy costs and lower supernatant quality due to dissolved solids. Thermophilic digestion has caused more odour inconvenience and the process stability is weaker compared to mesophilic digestion. For this reason, it is only in operation in a few waste water treatment plants in the world. Examples in the Baltic Sea Region include Braunschweig (Germany) and Malmö (Sweden). After several years of experimental operation with municipal waste water sludge, Malmö has chosen the mesophilic solution (LaCour et al., 2004).

Thermophilic temperature has been extensively tested with sewage sludges from municipal waste waters in laboratory, pilot and full scale for more than 30 years – unfortunately without success. Often, the high energy consumption causes problems meaning that only in warmer regions thermophilic digestion would be suitable. Accordingly, the following discussion focuses on the mesophilic temperature range only.

In principle, there are two main mesophilic digestion methods: wet and dry digestion. Wet digestion is the conventional way, whereas the use of dry digestion is restricted to handling mixed municipal biodegradable waste or garden waste. As dry digestion is not applicable for sludges originating only from municipal waste water treatment, it is not discussed here in more detail.

The organic feed material to wet digestion is often a mixture of primary and excess sludges, fed to an airtight reactor, stepwise or continuously. The most commonly used anaerobic digester is equipped with heating and mixing devices. The process principle is presented in Figure 4-1.

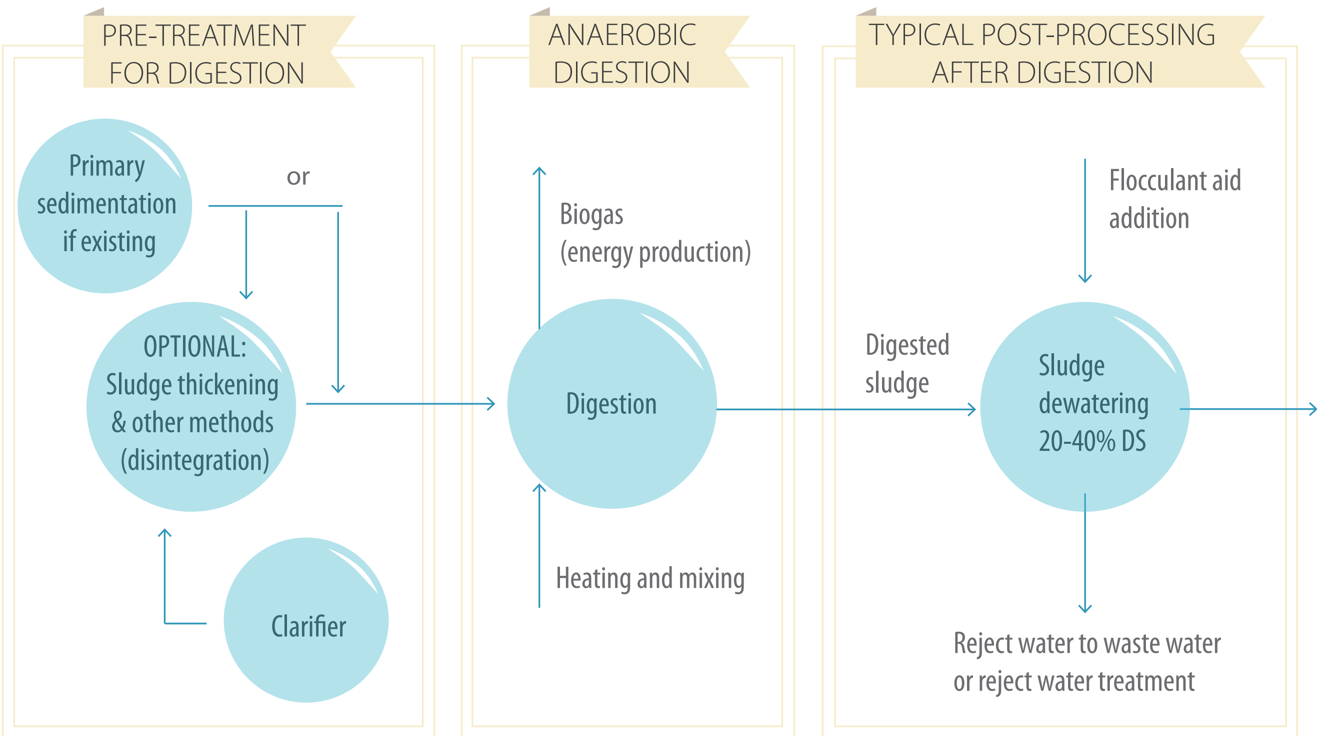


Figure 4-1: Anaerobic digestion process in the sludge handling chain.

4.2 MESOPHILIC DIGESTION PROCESS

The mesophilic treatment process is widely used and the temperature is normally about 35–40 °C. The main advantages are good process stability and supernatant quality with reliable operation experience.

Digestion takes place in one or several reactors, which can be fed in parallel or in a row with a typical retention time of between 20 and 25 days. The minimum retention time is around 14 to 15 days – lower retention time normally reduces the gas production, although some treatment plants are operating with retention times under 14 days without any reduction of gas production. In these cases, the sludge is very well biodegradable; for example, the share of primary sludge is big or there is hydrolysis taking place already in the primary sedimentation due to too high volume. Also, it is possible to reduce the minimum detention time with some pre-treatment methods.

As for all the other stages of sludge handling − also for digestion – the characteristics of the sludge that is to be treated are crucial. Primary sludge is easier to digest and easier to dewater compared to excess sludge that consists of bacteria from the activated sludge process. The digestion of excess sludge requires a longer detention time.

4.2.1 The digestion reactor

The digestion reactor is always equipped with a mixing and a heating device to guarantee good mixing and constant temperatures. The digested sludge can be removed from the reactor either by pumping or by gravity with telescopic tubes. The surface foam is removed with telescopic tubes by gravity. The reactors are normally concrete or steel tanks – depending on the reactor volume and raw material costs – and are usually above ground and insulated in order to maintain an even temperature in the reactor.

The shape of the reactor is an important design criterion, the details of which issue are dealt with in many waste water engineering handbooks. For example, the height of the proper shape reactor should often be slightly bigger than the diameter to ensure proper mixing and operation conditions. There are different shapes used in the Baltic Sea Region. The 'egg shape' is common, especially in Germany, while in other countries cylinder-type reactors are often used.

Due to the long detention time, the digestion of sludge requires large reactors which require quite a lot of space. In addition to the reactor tank(s) for balancing fluctuations in the biogas production, the produced biogas also requires a gas storage, which also needs additional space (see section 4.5). Typical diameters of reactors and gas storages are 6–15 m and the area demand for digestion process for a large waste water plant is approximately 25–35 m by 30 –40 m. All reactors can be placed outdoors but need to be insulated. Pumps and other auxiliary equipment should be placed indoors, typically underneath the reactors or in separate pump houses.

Figure 4-2: Different shapes of digesters in Lübeck, Germany and Riga, Latvia. Photos: Entsorgungsbetriebe Lübeck and SIA Riga Udens.

4.2.2 Pre-treatment and feeding to digestion

The needed pre-treatment mainly depends on the sludge type and quality. Thickening – the common pre-treatment method – is described in chapter 3. Excess sludge, in particular, is thickened mechanically to achieve a higher solids content.

A mixture of primary and excess sludges should reach a dry solid content of between 4–7 % before digestion; however, lower DS contents are sometimes safer for operation. Increasing the DS content causes lower energy consumption for heating and a reduced digestion time. The reactor volume of the digester can be reduced substantially, and it is possible to use this free volume for co-fermentation. Thickening is always limited by the pumpability of the sludge, the structure of the digester and the need to achieve good mixing (see section 4.2.4).

Additional possibilities of pre-treatment are chemical, thermal or mechanical pre-treatment procedures. In general, the different processes have common aims: to increase the gas production and to reduce the volume needed for digestion. Some of the processes have also shown promising results in reducing filamentous bacteria in the digester. Although many of the methods are still at the testing phase, the most promising have commercial applications. The most used are thermal hydrolysis (e.g. the Norwegian process Cambi) (Walley, 2007); ultrasonic treatment (Xie et al., 2005); and mechanical disintegration (Machnicka et al., 2009) – one example being HPF-fragmenting installed at Envor Oy, Forssa, Finland. Other disintegration methods are also possible.

When considering pre-treatment, its impact on the reject water quality must be taken into consideration. As the pre-treatment breaks the sludge structure on a cellular level, the amount of suspended solids − COD, BOD and nitrogen − in the reject water can become even several times higher than without the pre-treatment.

Continuous or regular intermittent feeding is beneficial to the digester's operation since it helps to maintain stable conditions in the digester. Uniform feeding and multiple feed point locations in the digester can alleviate or reduce shock-loading to the microorganisms. Excessive hydraulic loading should be avoided with a feeding and mixing tank immediately before the feeding pipe into the digester. Excess hydraulic loading would decrease detention time, dilute the alkalinity necessary for buffering capacity and require additional heating energy. Often, a stable hydraulic flow into the digester is maintained, controlled and ensured by recycling part of the liquid in the reactor to the feed tank (Burton et al., 2003, Hammer; Hammer, 2001, and Vesilind, 2003).

It is also possible to enhance the performance of the digesters by thickening a portion of incoming sludge to increase the retention time of the solids. Recirculating a portion of the digested sludge and co-thickening it with incoming primary and excess sludge, or with the separate thickening of excess sludge are the most common alternatives in this respect (Burton et al., 2003).

Figure 4-3: Ultrasonic disintegration in Gdansk, Poland. Photo: GIWK.

4.2.3 Heating

To ensure optimal conditions for bacteria, it is important to ensure a constant temperature in the digester, as temperature variation or poor insulation reduces biogas production.

The heating of the sludge and reactor can be implemented either with conventional heat exchangers and sludge recirculation or with batch feeding. The biogas produced in the digestion process is primarily used for the generation of electricity in the combined heat and power unit (CHP). The thermal energy produced

Figure 4-4. Photo: Shutterstock.com/Chris2766.

Good to know:
Reducing conditions in the digester and heating the sludge induce chemical reactions. Especially in tubes and heat exchangers, the formation of MAP (magnesium ammonium phosphate) and vivianite (iron phosphate complex) can cause problems.

at the same time is used to heat the feed sludge and digester reactor. If the incoming sludge has a relatively low temperature (5–10 °C) for a long time period during the year, the feed sludge is usually pre-heated in the feeding and mixing tank which, in turn, is heated with tubular or lamella types of heat exchangers and sludge recirculation to reach the needed mesophilic temperature range of 35–40 °C.

In batch heating, each batch is heated in separate tanks with steam or hot water and fed stepwise to the digesters. It is not necessary to recirculate the sludge with the batch feeding process. In both cases, additional thermal energy is produced by burning biogas in a hot water boiler when needed.

4.2.4 Mixing

Effective mixing is important when considering a proper process operation. Mixing the digester contents enhances its operation by reducing thermal stratification, dispersing the incoming sludge for better contact with the active biomass, and reducing scum build-up. Mixing also dilutes any inhibitory substances or adverse pH and temperature feed characteristics, thereby increasing the effective volume of the reactor.

The type of mixing equipment is important for the successful operation of anaerobic digestion; the optimal mixing equipment depends on the shape of the digester and the dry solids content of sludge, for instance. Various systems for mixing the contents of the digester have been applied with the most common types involving the use of: (i) gas injection using draft tubes (series of large diameter tubes into which the digester gas is released causing the biomass to rise and mix); (ii) mechanical stirring with rotating impellers; and (iii) pumping and recirculating the contents of the digester with external mounted pumps which usually withdraw the liquid from the top centre of the tank and re-inject it through nozzles tangentially mounted at the bottom of the digester (Vesilind, 2003). Circular pumping is only recommended as a support for the main mixing or as emergency mixing.

The principles of mixing are defined in the design and construction stage; in addition, detailed instructions on how to operate mixing in each case are included in the operating instructions provided by the technology supplier. While each mixer has advantages and disadvantages, the right choice should be made with the shape of the digester and the characteristics of the building under consideration.

4.3 OTHER RELEVANT INFORMATION ON DIGESTION

Operation, maintenance, environmental and safety aspects

The operation of the digester takes place continuously, only feed and discharging can take place in a day shift, for example. Continuous feeding is possible with a buffer tank for primary and excess sludge or direct feeding. With mechanical thickening operating only during day shift, discontinuous feeding cannot be avoided.

The operation of an anaerobic treatment process requires more biotechnical skills than the operation of other sludge handling equipment like thickening or sludge dewatering. Unless special attention is paid to it, this technology is a potential source of malodorous air emissions; and since the biogas is also explosive, special safety control measures must be carried out. Electrical equipment should be protected with explosion protection devices. Moreover, the operating and maintenance personnel must be well trained for normal operation as well as for exceptional situa tions usually associated with start-up, shut-down and maintenance operations. A systematic safety plan including, but not limited to the regulation of hot work permits (for e.g. welding), and regular safety inspections of competent safety experts of the plant are absolutely necessary.

Environmental aspects are related to the air emissions of biogas. For start-up and shut-down phases, maintenance interventions and emergency situations, there is usually a by-pass route for biogas equipped with a gas scrubber or a flare, where these gases are either washed or incinerated prior to releasing them to the atmosphere.

Costs, unit consumptions and manpower

Anaerobic digestion is mainly applied in medium-size and large treatment plants. Investment costs range from EUR 5 million to EUR 15 million, including biogas utilisation with CHP. For very large plants, the investment costs can be much higher, up to 50–80

Figure 4-5. Photo: Shutterstock.com/Hansenn.

million euros for a waste water treatment plant with more than 1 000 000 population equivalents. The technical lifetime of the mechanical and electricity equipment is usually 15–20 years and 30–40 years for the concrete buildings. Installed power is approximately 100–150 kW and the electrical power consumption some 100–400 kWh/t DS; however, this is compensated by the electrical power production from biogas. Hence, digestion is a net producer of energy and the own consumption of digestion mixers and pumps should be taken into account when assessing the net economic benefits of this process. This unit process requires 2–3 persons more; also, additional skills and special competences for anaerobic processes and the maintenance of explosion risk zones are needed beyond the normal operation of the waste water treatment plant.

Use in the Baltic Sea Region

This technology is widely used in the Baltic Sea Region at medium-size and large waste water treatment plants. Also, some small plants are planning to build a digester. As the break-even point to build a digester has shifted, it may be also economical for smaller plants. Sometimes, several smaller municipalities have agreed to build a common digestion plant to serve them.

In Estonia, digestion has been installed in Tallinn and Kuresaare, with a digestion plant under construction Tartu. In Latvia, there are digesters in Riga and Limbazi. In Sweden and in Finland, digestion is installed in bigger cities like Stockholm, Gothenburg, Helsinki, Tampere, Espoo, Kuopio, Jyväskylä and Hämeenlinna. In Poland, there are digestion plants in Gdansk, Lublin and Szczecin. See Table 5-2 for PURE partner comparisons in the use of digestion (together with dewatering).

4.4 SUMMARY OF ANAEROBIC DIGESTION

Mesophilic digestion is suitable for medium-size and large waste water treatment plants, and sometimes for smaller waste water treatment plants. It is possible to reduce the sludge volume considerably and gain biogas for energy supply. Digesters should be constructed with enough volume allowing a detention time of more than 20 days. For larger plants, a reduced detention time is also possible. The dry solids contents should be optimised with good mixing.

In addition to the investment costs (that depend on the size of the plant) and to the power consumption, it has to be taken into account that digestion produces a significant amount of reject water that increases the nitrogen and COD loads in the waste water treatment plant.

4.5 BIOGAS PRODUCTION AND TREATMENT

Biogas is taken from the top point of the digester. It has an average content of 58–64 % of methane (CH_4), 30–40 % of carbon dioxide (CO_2), and a small amount of water and hydrogen sulphide (H_2S). In special cases, for example where the food industry's share in the waste water is high or when co-fermentation is done, the methane (CH_4) content can be up to 70 %. The calorific value of methane (100 %) is 10 kWh/m³ and of biogas between 5.8–6.4 kWh/m³.

With the proper design of the gas collection, storage and utilisation systems, the unpleasant odour of the biogas can be avoided. Gas production is estimated based on the volatile solids removal rate. Gas production is dependent on the used substrate quality and amount of volatile solid (VS) organic material. Also, the biological activity and mixing conditions have a significant effect. Typical gas production for the sewage sludge is around 400–450 m^3 per tonne VS reduced. Primary sludge has a much higher biogas potential than excess sludge, and the higher detention time in primary sedimentation may have a direct positive influence on biogas production in the digester.

Good to know:
There is always the threat of an explosion when working with biogas. All aggregates, therefore, must be protected against explosion and warning signs must be highly visible.

It is also possible to increase biogas production by adding co-ferments like grease, untreated (and highly concentrated) sewage and crushed biowaste to the digesters when there is enough space, for example with a digestion time of more than 25 days. It is important that the co-ferments are treated beforehand and that the waste water treatment plant has enough capacity. Especially, the nitrogen load from dewatering will increase. Co-ferments should only be used if the legislation situation is clear. It may be possible that agricultural disposal is not allowed while using co-ferments, or that a permit is required from the relevant authorities.

Figure 4-6: Gas flare, gas storage tank and digesters in Lübeck, Germany.
Photo: Entsorgungsbetriebe Lübeck.

A benchmark for digesters is the amount of degradation of organic matter in the sludge. A degradation of 50 % of organic matter is considered as good performance.

Methane is a greenhouse gas — a much more effective one than carbon dioxide. All biogas plants must be equipped with a flare for safety reasons in order to be able to evacuate excess biogas in all circumstances in a safe manner. The flare must be designed for the maximum biogas amount.

Good to know:
The digester gas collection and distribution system should be maintained under positive pressure to avoid the possibility of explosion if the gas is inadvertently mixed with ambient air. Mixtures of air and digester biogas containing methane concentrations ranging as low as 5 % are potentially explosive. Gas storage, piping and valve arrangements should be designed and maintained in such a way that when the digester sludge volume changes, the gas – not air – will be drawn to the digester (Vesilind, 2003).

4.5.1 Gas removal and cleaning

The biogas is removed from the digested sludge by air stripping in the gas removal unit before the sludge is fed further to the intermediate storage. Digester biogas also contains small amounts of water and hydrogen sulphide (< 0.01 %). It causes corrosion in CHPs, tubes and in the gas storage. The removal of sulphur is recommended; also, one (or several) drop separators should be installed. If the requirements are very high, a gas dryer is needed in order to remove nearly all the water in the biogas.

The treatment gas is then pumped in a storage tank. The minimum volume of the gas storage is equal to 1–2 hours of gas detention time. A bigger volume gives more flexibility for use in the CHPs. The gas storage is often constructed of a double plastic membrane.

Figure 4-7: Different types of gas storage tanks in Riga, Latvia and in Szczecin, Poland. Photos: SIA Rigas Udens and ZWiK Szczecin.

4.6 ENERGY UTILISATION

Biogas is renewable energy. The combined heat and power plant (CHP) unit uses the biogas unit uses the biogas to produce electrical energy, most often with gas motors or micro turbines. Modern CHPs have an efficiency factor over 40 % for electrical energy production. The surplus heat of the machine and of the exhaust gas can be used to heat the sludge that is fed to digestion, to heat the operation building, and dry the sludge. If a district heating system exists, it is also possible to sell the heat to a nearby heat supplier.

Electrical energy can be used on-site or sold outside the plant, depending on the system in the operator's country. The electrical efficiency factor is important since plants with less than a 35 % efficiency factor can be considered out-of-date. On the other hand, a CHP with high electrical efficiency is less efficient for heat production.

Additional heat may be required, especially in wintertime. It can be produced with a permanent or temporary hot water boiler, where biogas, natural gas or light fuel oil can be used. An innovative method is the use of a heating pump in combination with waste water heat at the plant.

A modern CHP is only one of the possibilities to increase biogas production. Optimised digestion and energy management are the basis for energy saving. Some plants (e.g. Hamburg) are already able to produce more electricity and heat that they need, or cannot use 100 % of the biogas, so that they feed biogas into the natural gas system.

To increase biogas production, the volume of primary sedimentation has to be increased. It is possible that as a consequence, denitrification will lack a carbon source so that an external source must be used. An example of a good carbon source is ethanol from a brewery. Other possibilities of increasing the biogas production are:

- avoiding high sludge age in aeration;
- optimising mixing to avoid dead zones in the digester;
- optimising the heat exchanger and insulating the digester for better temperature distribution;
- disintegrating excess sludge before digestion to increase the efficiency; and
- the additional use of co-fermentation.

Also, the operation of the CHP can be optimised with a gas tank of sufficient volume and a heat buffer, so that the CHP can always be operated in the optimal efficiency field.

Figure 4-8 CHPs in Lübeck, Germany and in Szczecin, Poland. Photos: Entsorgungsbetriebe Lübeck and ZWiK Szczecin.

Figure 4-9: Energy central with CHP, gas flare and heating system in Riga, Latvia. Photo: SIA Rigas Udens.

4.7 AEROBIC STABILISATION

Sludge can be stabilised – as an alternative to anaerobic digestion – by long-term aeration that biologically destroys volatile solids. Long-term (or extended) aeration takes place in aeration tank and can therefore also be referred to as 'simultaneous aerobic digestion'. Also, aerobic stabilisation methods operating at higher temperatures and in separate tanks have been developed. Aerobic digestion produces sludge suitable for various disposal options.

Simultaneous aerobic stabilisation can be realised by increasing the retention time at the biological treatment up to 25 days with a good oxygen supply (ATV-DVWK-M 368E, 2003). This process does not need any special competence beyond the normal operation of a waste water treatment plant. The method is seldom used in the Baltic Sea Region – mainly in Germany at some small and medium-size plants without primary clarifiers (Einfeldt, 2011).

It is possible to apply other aerobic stabilisation methods, for example aerobic thermophilic stabilisation (also mentioned in section 6.2.2), which is designed for medium-size and large plants. A constant mesophilic or thermophilic temperature and a good oxygen supply guarantee that aerobic stabilisation takes place.

The drawback of the aerobic digestion process is the high cost due to energy intensive aeration. Also, no biogas is produced.

4.8 EXAMPLE: PURE partner sludge handling solutions – LÜBECK, Entsorgungsbetriebe Lübeck, central waste water treatment plant (ZKW)

The Hanseatic City of Lübeck, Germany, operates two waste water treatment plants. Sludge from the smaller plant (30 000 population equivalents, PE), which is situated in the seaside resort Travemünde, is shipped to the Central Plant (350 000 PE). This is the third largest in the County of Schleswig-Holstein. It is equipped with a modern 2-step-filtration, which enhances the results of biological nitrogen and chemical phosphorus removal. The values of the typical wastewater parameters exceed the European and the German requirements by far. A biological phosphorus removal process is not applied. The annual output of digested and dewatered sewage sludge is approximately 9 000 tonnes (dry solids, DS).

The plant is equipped with a large primary treatment unit. Primary sludge is fed directly to the digester with a DS content of 2.5–4 % without using static thickeners. The excess sludge from the biological treatment (activated sludge) is thickened mechanically with belt thickeners to approximately 5.5 % at low polymer (1–3 g/kg DS) and energy consumption rate.

Sludge is stabilised in mesophilic digesters with a retention time of at least 18 days at 37–39 °C and a dry matter content of 2.5 %. As an additional external substrate, fat from the separators is dosed during the day. The produced biogas contains approximately 62% methane, it is dried and desulfurised before storing in a gas tank of 4 000 m³, which has proven to be very helpful for the CHP operation. Three new CHPs (combined heat and power plants) with an electrical power rate of 844 kW produce electricity and heat totalling 10 GWh each. The electrical efficiency at the rated power level reaches 41.7 % and the rate of self-sufficiency regarding the total electricity demand of the wastewater plant meets nearly 100 %. Also, the coverage of the total heat demand is more than 100 %.

Figure 4-10: Digester at central waste water treatment plant Lübeck. Photo: Entsorgungsbetriebe Lübeck.

Sewage sludge is conditioned with lime and iron, and dewatered by the chamber filter presses. A DS content of 36–39 % is achieved. Currently, the entire sludge is used as a fertiliser on farmland. Transport and disposal is outsourced to an external contractor.

The future of the agricultural use of sludge in Germany is very controversial. To date, no problems have occurred with heavy metal limits, except for high levels of copper originating from household installations. New limits will likely hamper the use in agriculture, but it is expected that Lübeck's disposal practice will not be closed down. The disposal of sewage sludge at landfills has been banned in Germany since 2005, so that the only remaining alternative left after agricultural use is incineration.

Actual plans in connection with the sludge treatment aim at the constructional renovation (if required) of the digesters and the introduction of vertical tube mixers. After this, the focus will be on the general future of sludge disposal, including decisions on new dewatering devices.

Figure 4-11 The central waste water treatment plant of Lübeck. Photo: Entsorgungsbetriebe Lübeck.

5. SLUDGE DEWATERING

Photo: Shutterstock.com/Marteric.

5.1 INTRODUCTION

The sludge dewatering process is relatively simple: increasing the dry solids content of the sludge with different types of equipment. This unit process always requires the use of at least some flocculant aid that keeps the excess sludge flocculated in the dewatering unit. Sometimes, coagulation chemicals such as iron or aluminium salts are also added in order to enhance the efficiency of flocculant aids (polymers) and reduce the consumption of them in sludge dewatering. Some research projects are developing dewatering methods without any chemicals; however, the separation effect and reliability are not yet sufficient.

Indicative amounts of flocculant aid consumption in this section are presented in connection with each dewatering technology; the consumption depends more on the type and dewatering properties of the sludge than the dewatering equipment. Regardless of the sludge dewatering technology, laboratory measurements and full-scale tests focusing on sludge and filtrate are needed to obtain more reliable information on the choice of the right flocculant aid and the dosed amount, and also for the optimisation of a dewatering unit.

After dewatering, the dry solids content of the sludge is usually between 19 % and 30 %. Depending on the dewaterabilty, it is possible to reach a dry solid content of up to 40 %. With chamber filter presses, for example, this higher dry solid content is reachable by conditioning with lime. The maximum dry solid content can be determined in a laboratory. After reaching the maximum DS content with dewatering, the water left in the sludge is bound in the cells and can only be reduced with sludge drying.

One factor for low dry solids content in dewatering is biological phosphorus removal. Bacteria that are able to remove phosphorus from the waste water produce extra-cellular polymeric substances (EPS), which are very difficult to dewater. These structures can only be destroyed with disintegration (see section 4.2.2). In addition to the lower dewatering result, the chemical consumption of the flocculant aid in dewatering increases because of the EPS.

Good to know:
Especially in larger plants, dewatering should be secured with a back up device available in case of malfunction.

The following sections describe the available good solutions of sludge dewatering. Centrifuges and belt filter presses are currently the most popular dewatering methods in municipal waste water treatment plants due to their good operation and cost efficiency. Chamber filter presses are expensive compared to other presses, and are therefore used more in large applications elsewhere – in the mining industry, for instance. Hydraulic presses, originally developed for the food industry with high hygienic demands, are also expensive.

Screw presses are most suitable and used for sludges containing fibre material from the pulp and paper industry. Today, there are also some screw press applications in the Baltic Sea Region, especially in small and medium-size municipal treatment plants. They have been used in Finland (e.g. Viitasaari, Kannonkoski, Ranua, Tuusniemi and Pylkönmäki); Estonia (e.g. Kohila, Võru, Kallaste and Tapivere); and Sweden (over 20, e.g. Sollefteå, Gnosjö, Hammerdal, Hoting and Sorsele). As both the investment and operation costs are low, screw presses are suitable for smaller plants. For medium-size and large plants, this equipment is not as suitable as centrifuges or belt filter presses for dewatering sludge from municipal waste water treat-

Good to know:
Biological phosphorus removal reduces the dewaterability of the sludge. Chemical phosphorus removal can thus be economically realistic as it reduces the sludge's disposal and transport costs. On the other hand, biological phosphorus removal allows the recovery of phosphorus from the waste water more easily (see chapter 11). Also, the amount of sludge is smaller with biological phosphorus removal than with chemical precipitation.

Good to know:
A high excess sludge percentage in dewatering deteriorates the dewatering result and strongly increases the polymer consumption. Also, aerobic stabilisation or a detention time of over 20 days in the digester increases polymer consumption (Kopp, 2010).

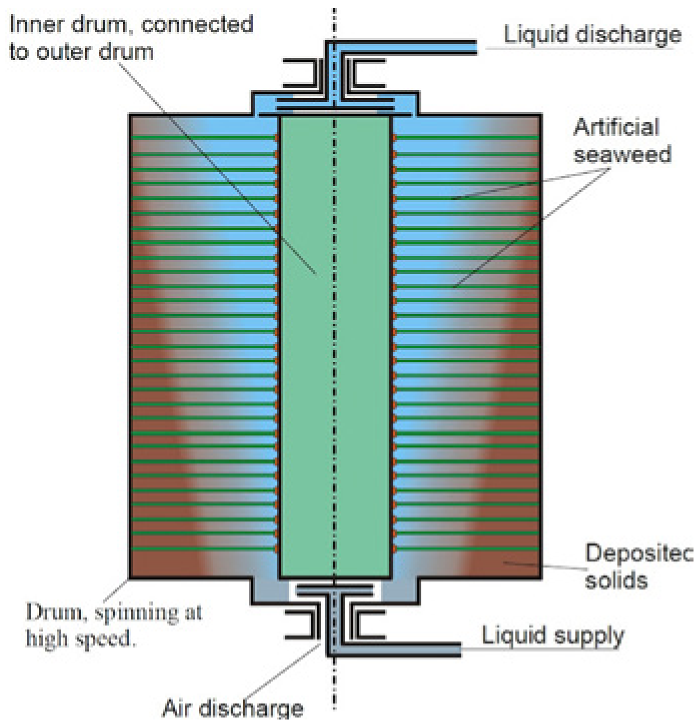


Figure 5-1: Scheme of the innovative 'Rofitec' method.
Picture: Technical University Berlin.

ment plants. In some plants, a substantial amount of suspended solids is lost with reject water from this type of dewatering equipment; this significantly increases the internal loading of suspended solids of the whole waste water treatment plant.

The achieved DS content, energy consumption and chemical consumption of dewatering vary with the type sludge – different sources give different information on these parameters. In this publication, a synthesis of numerical data from a number of sources (PURE Pöyry report, Burton et al., 2003 and DWA M-366 Draft, 2011) concerning dewatering is presented, including data from PURE project partners. The results of PURE partner waste water treatment plants and examples of waste water treatment plants where each technique is applied, are shown at the end of the chapter.

Good to know:
The temperature is in direct relation to the dry solid content after dewatering. Studies have shown that the dry solid content after dewatering with a sludge temperature of about 48 °C is up to 5 % higher than with 20 °C (Kopp, 2010).

Innovative methods:
Manufacturers and universities are working on developing dewatering systems without chemical flocculant aid addition. This is especially topical in Germany, where there is an active discussion on the use of polymers in dewatering sludge that will be disposed of in agriculture. Furthermore, flocculant aids cause high costs for the operators. Different solutions are under investigation. One example is 'Rofitec', developed by the technical university of Berlin, which does not need any flocculant aid. Unfortunately, the separation effect is still not sufficient (Ilian et al., 2011).

Innovative methods:
Treatment in reed beds is sometimes used as an alternative to the mechanical sludge treatment in small and medium-size waste water treatment plants in the southern parts of the Baltic Sea region (Germany, Denmark, Sweden). Effective dewatering, mass reduction and hygienisation of sludge can be reached in aerobic conditions through mineralisation and evaporation from the reed in shallow sewage sludge ponds. The end product can be used in landscaping as well as in agriculture. In suitable climatic conditions this method provides good dewatering results without external energy or chemical consumption. Some external energy is of course needed for the pumping of sludge to the ponds and reject waters back to the waste water treatment process. Also, at certain periods, the sludge ponds have to be emptied. Treatment in reed beds can be applied for non-digested or digested sludge (or for a mixture of them). (Nielsen, 2007; Schillinger, 2006).

Non-food non-fodder short rotating plantations (SRP's) have also been developed for sludge utilization. Especially willow and poplar trees have been found as suitable species as their water and nutrient uptake is high. The idea of the SRP's is that the utilization of pre-treated sludge is outsourced to farmers who utilize the nutrients and water of the sludge in biomass production. (BIOPROS, 2008).

5.2 CENTRIFUGE

Operating principles and space requirements

The decanter centrifuge with its continuous feed and sludge output is the standard centrifuge type. High g (corresponding to the high multiples of the force of gravity, g) centrifuge models are favoured to achieve high dry solids content. The basic construction of a decanter centrifuge is shown in Figure 5-2. The key elements are the bowl, which includes cylindrical and conical sections, the conveyor screw inside the bowl and the drive units to rotate them. The casing surrounding the bowl acts as a protective and noise suppression barrier, and channels the dewatered sludge cake and separated clarified liquid – or centrate – out from the unit.

Dewatered sludge cake discharges out from the bowl through a port located in the small diameter end of the conical section. A small difference in the rotational speed between the bowl and the conveyor allows the accumulated sludge cake to roll, thicken further and be transported from the cylindrical section up the cone for discharge. The centrate outlet ports include adjustable height overflow weirs, with which the liquid level inside the bowl can be adjusted.

The main factors affecting the decanter centrifuge performance are:

- the centrifugal force;
- the clarification area and bowl liquid depth, i.e. pool depth, to capture the solids from the feed;
- the design of the conical bowl section and the conveyor screw;
- the flight angle and differential speed of the conveyor screw inside the decanter for proper sludge dewatering and conveyance; and
- the hydrodynamic design, i.e. the parameters affecting turbulence.

The space requirement depends on the capacity; typical ranges are: width 2–5 m; length 7–15 m; and height 3–6 m, including space needed for maintenance. This equipment always requires indoor installation.

Suitability for different types of sludges, and different types and sizes of operation

Centrifuges are usually used for dewatering digested or aerobically stabilised sludge; it is also possible to dewater other types of sludge. In the past, centrifuges have been used especially in large waste water treatment plants; today, however, they are increasingly being used also in medium-size and small plants. The process is compact and closed, tidy and reliable, and models with small capacity are also now available. There are mobile versions of centrifuges placed in trucks, which can be used for dewatering in several small waste water treatment plants, enabling cost sharing between the operators.

Dewatering result

The dewatering result mainly depends on the type of sludge. Primary sludge is much easier to dewater than a mixture of primary and excess sludge, aerobically stabilised or digested sludge. Centrifuges are able to dewater primary sludge to a dry solid content of about 32–40 %; a mixture of primary and excess sludge to a DS content of about 26–32 %; aerobically stabilised sludge to a DS content of about 18–24 %; and digested sludge to a DS content of about 22–30 %.

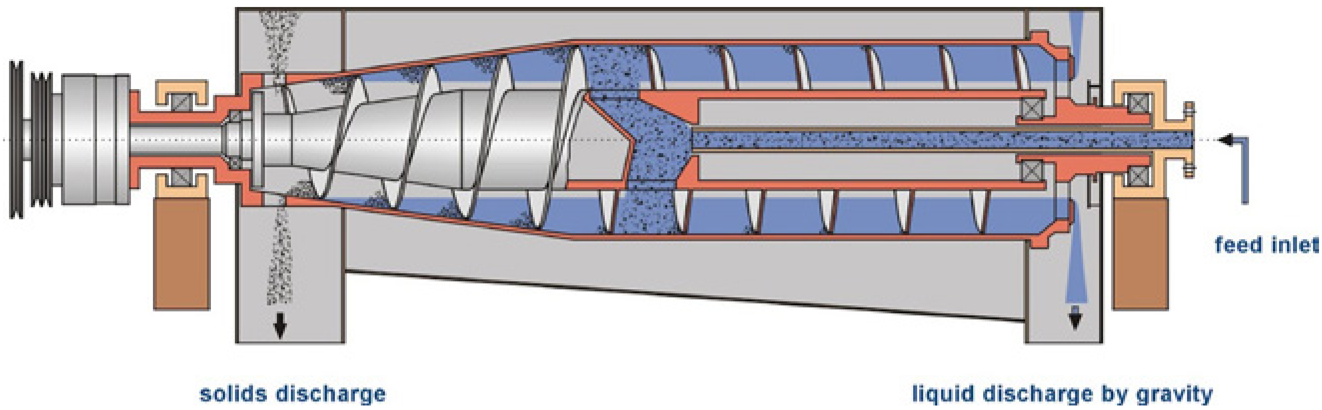


Figure 5-2: Diagram of a decanter centrifuge. Picture: Company Flottweg SE.

Operation, maintenance, environmental and safety aspects

Centrifuge dewatering can be operated continuously (24/7). Only small buffering with a mixing tank is recommended to achieve stable conditions. This is advantageous especially for large waste water treatment plants. For medium-size treatment plants, the dewatering takes place during one or two shifts a day (8 or 16 hours per day; 5 days per week). A buffer tank is recommended; also, a direct feed out of the digester to the dewatering device is possible.

Centrifuges require daily cleaning with 5–15 minutes of washing – usually when the centrifuge is stopped between shifts. The washing procedure can be avoided with continuous operation.

Maintenance requirements include an intermediate intervention after 2 000 to 4 000 operation hours (or at least once a year as a minimum) and a major intervention after 8 000 operation hours. In the intermediate maintenance, the engine packing and oil are changed and the centrifuge is lubricated. In the major maintenance, the engine bearings are changed and the changeable wear plates and hardened metal surfaces are checked.

The diameter and rotational speed of the bowl affect the available centrifugal force, which separates the sludge particles from the bulk sludge suspension inside the bowl. High centrifugal force models, typically higher than 2 500 g:

- run at higher speeds and commonly have a smaller diameter but longer bowls than conventional models used for a similar type and amount of sludge;
- have higher demands on the main structural elements, bearings and drive units, which make these units more expensive;
- consume more electrical power, though in more recent designs the inbuilt centrifuge energy recovery systems attain some savings; and
- reach higher sludge dry solids content.

Primary sludge has higher torque requirement and potential for material erosion than excess sludge. Changeable wear plates on the tip of the screw and hardened metal surfaces in areas affected by heavy wear reduce maintenance costs.

In municipal sludge handling, centrifuge requires flocculant aid to sufficiently speed up and enhance water separation from the solids, the final consistency of the sludge and a low content of solids in the centrate. The type and properties of the flocculant

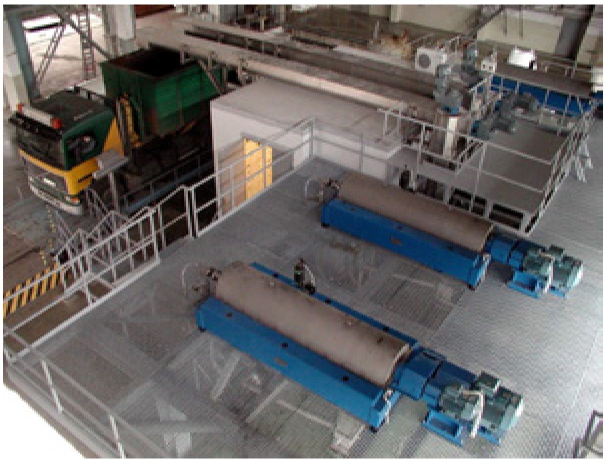


Figure 5-3: Decanter centrifuges in Riga and Jurmala, Latvia. Photos: SIA Rigas Udens and PIU Jurmalas Udens.

aid are tested for each sludge type and the dewatering equipment. For instance, the flocculant aid for the centrifuge needs shear stability because of the g forces. Centrifuge does not use especially high amounts of flocculant aid, and can handle higher-than-design loadings with increased flocculant aid dosage, although the cake solids content may be slightly reduced (Guyer, 2011).

There are no particular environmental concerns with this type of equipment. With many models, the noise of the equipment is relatively high and personal ear protectors are needed for occupational safety reasons.

Costs, unit consumptions and manpower

Investment costs usually range between EUR 100 000 and EUR 250 000 depending on the capacity. The technical lifetime of the equipment is usually 15–20 years; however, if the preventive maintenance of the bearings and other wearing parts of the equipment is not properly taken care of, this can be reduced in some cases to 10–15 years.

Installed power is approximately 20–90 kW (depending on the capacity) and the electrical power consumption of this unit process is approximately 30–35 kWh/t DS, i.e. somewhat higher than the other alternative sludge dewatering methods. It also depends on the actual operating time of the equipment. Chemical consumption ranges from 4 to 14 kg flocculant aid per tonne of DS. The consumption of flocculant aid depends on several factors, such as the consistency of the sludge, the degree of digestion, the ratio of primary sludge/excess sludge and the amount of organic matter in the sludge. The choice of the right cationic polymer as the flocculant aid reduces the consumption. Changing conditions at the plant (or at the digester) cause changes in the surface charge distribution of the sludge, which can increase or decrease the polymer consumption. This unit process does not need any additional manpower or special competences beyond the normal operation of a waste water treatment plant.

Figure 5-4: Demounted decanter centrifuge in St. Petersburg, Russia. Photo: Lotta Ruokanen, HELCOM.

5.3 BELT FILTER PRESS

Operating principles and space requirements

The key elements of a belt filter press are the frame that supports the integrated sludge feed, the upper and lower belt systems for gravity drainage and pressing, the belt guidance and wash systems and the sludge discharge. Modern models often include an integrated enclosure to suppress the splashing of sludge and filtrate and the release of vapour, mist and malodorous gases. A proper design can also include a separate local air exhaust hood above the belt filter press unit.

Sludge fed to the unit is spread with a chute across the width of the belt in the gravity drainage section. Sometimes, the chute has integrated guides welded onto it to aid the even spreading of sludge.

Belt filter presses are offered in several options concerning the sludge feed arrangement, gravity thickening zone and sludge pressing section. In the horizontal dewatering section, the sludge has to dewater fast. The flocculant aid dosing has to be exact and effective to remove the maximum amount of water. This is more easily accomplished with primary sludge than with excess sludge. After this pre-dewatering in the horizontal dewatering section, the sludge is dewatered in the press sections.

The gravity drainage section with short retention time can, in principle, be integrated directly to the operation of the lower belt of the press. However, a long retention time and gentle sludge handling is typically required for thickening municipal sludge; for this reason, a large integrated gravity drainage section is built above the press section. Sometimes, even a separate gravity table unit, designed for gravity thickening on a moving belt, is installed before or above the belt filter press. The principal structure of a belt filter press is shown in Figure 5-5.

Good to know:
Sludges with changing properties cause high demands. Flocculant aid dosing has to be optimised. It is also possible to elongate the first section to guarantee pre-dewatering. If flocculation does not take place, sludge may slip out of the pressing zone. For this reason, many manufacturers require minimum dry solids content of the sludge that is to be treated with a belt filter press (3 %).

Space requirements depend on the capacity of the belt filter press; typical ranges are: width 3–6 m; length 5–10 m; and height 3–6 m, including space needed for maintenance. This equipment always requires indoor installation.

Dewatering result

The dewatering result is little lower than with centrifuges. Primary sludge can be dewatered up to 30–35 %; a mixture of primary and excess sludge up to 24–30 %; aerobically stabilised sludge up to 15–22 %; and digested sludge up to 20–28 %.

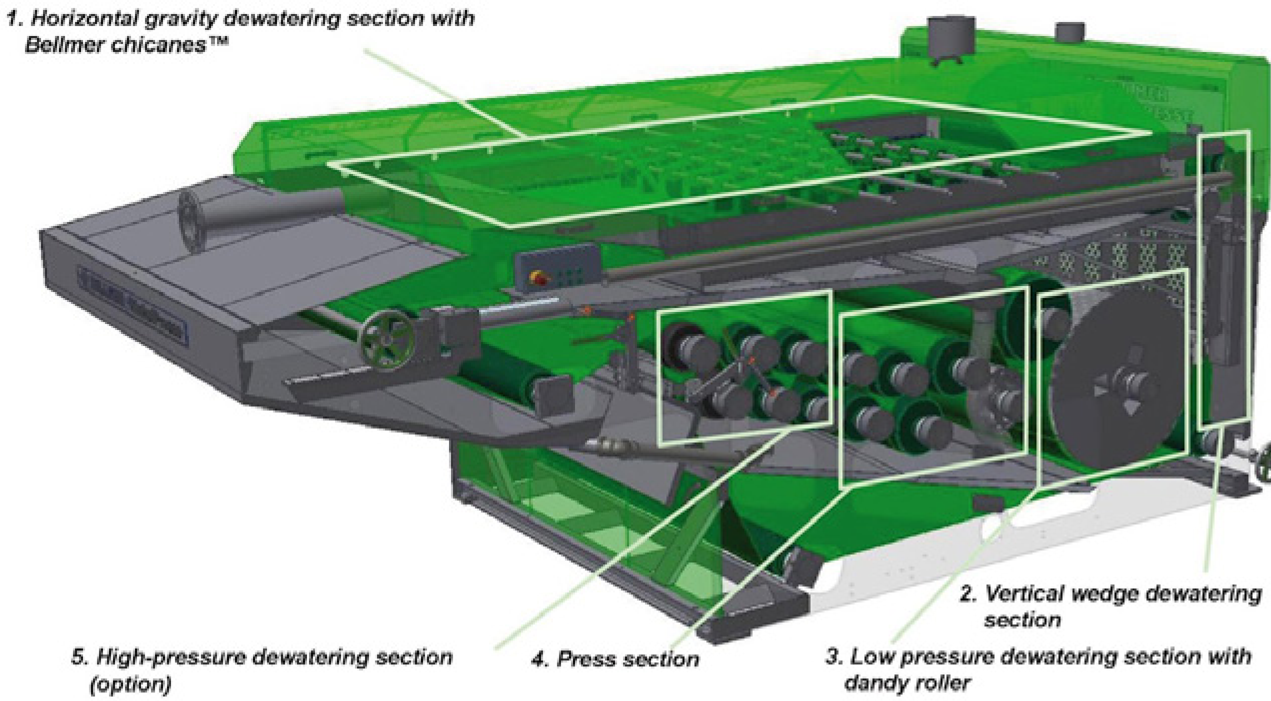


Figure 5-5 Scheme of a belt filter press. Picture: Company Bellmer GmbH.

Good to know:
Additional sections can be added to the belt filter pores for a better dewatering result and higher dry solids content.

Suitability for different types of sludges and different types and size of operation

Belt filter presses are often used for digested sludge; it is also possible to dewater thickened sludge with no intermediate digestion step. It is not recommended, however, to dewater sludge that has not been thickened with this technique.

This sludge dewatering equipment is extensively used in the Baltic Sea Region. And while it has dominated the market in small and medium-size plants, centrifuges are increasingly replacing it because of their compact and closed structure. However, there are also treatment plants serving up to 100 000 population equivalents, as in Tartu in Estonia, that still rely on belt filter presses. There are also mobile versions on trucks which can be used for dewatering at small waste water treatment plants so that costs can be shared between the operators.

Operation, maintenance, environmental and safety aspects

Belt filter press dewatering is designed for continuous operation (24/7), although operation in shifts is possible; in practice, many medium-size waste water treatment plants have chosen to operate dewatering during one or two shifts a day (8 or 16 hours per day; 5 days per week). A buffer tank equipped with mixing is recommended; if the press is not operated continuously, the volume of the tank should be increased. Stable conditions can be guaranteed with the buffer tank. Direct feeding out of a digester is also possible if the digester is fed continuously. If there is no digestion, primary and excess sludge should be thickened continuously with the same proportion to guarantee constant conditions.

Similarly to the belt thickener, the belt filter press needs continuous washing. This is done automatically with filtrate. It also requires cleaning or maintenance work typically every 1–2 weeks.

A belt filter press is a reliable unit when regular preventive maintenance is taken care of by the operating personnel. The gearboxes need oil changes and the belt rolls need proper lubrication according to the instructions of the equipment supplier. If the belts are operated by a hydraulic unit or the roller bearings are lubricated by a pressure lubrication unit, these units must be checked regularly. The belt is a wearing item and must be changed once in 1–2 years, more often if the sludge is very abrasive.

Local control panels and remote controls provide good flexibility to adjust the belt filter press and monitor its functions. Belt speed and sludge depth in the inlet end of the gravity drainage section are important parameters affecting performance, as are the automated monitoring and control of the upper and lower belt alignment. Sometimes, although the on-line monitoring of the filtrate quality has been carried out, the measurements have poor accuracy and are not suitable for the automatic fine-tuning of the flocculant aid dosing. Special units for monitoring water drainage from the belt in the thickening zone have also been offered; however, they are not very reliable in controlling the flocculant aid dosing.

There are no particular environmental concerns with this type of equipment.

Costs, unit consumptions and manpower

Investment costs usually range from EUR 80 000 to EUR 250 000 depending on the capacity. The technical lifetime of the equipment is usually 15–20 years, although belts and other wearing parts have to be replaced once in 1–2 years. The investment cost can rise due to the odour hood and increasing the capacity of different sections.

The installed power is approximately 20–50 kW with the electrical power consumption of this unit process being approximately 20–30 kWh/t DS. The consumption is marginal compared to the overall consumption of waste water treatment. It also depends on the actual operating time of the equipment. Chemical consumption is typically 4–12 kg flocculant aid per tonne of DS. Flocculant aid consumption is, on average, a little lower compared to the centrifuge but can vary depending on the characteristics of the sludge.

Figure 5-6: Sludge on the belt filter press in Szczecin, Poland. Photo: ZWiK Szczecin.

This unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

5.4 CHAMBER FILTER PRESS

Operating principles and space requirements

A chamber filter press consists of a series of filter chambers containing filter plates supported in a frame. The sludge is fed in a batch manner. Loaded filter chambers are forced together with hydraulic rams. The sludge is squeezed in few seconds by up to 60 bar pressure in the press. The dewatered sludge is then discharged from chambers by opening the filter plate and shaking cloth or plate. The chambers and filter cloth are washed regularly to ensure continuous good filtration results and a longer durability of the cloths.

Space requirements depend on the capacity; typical ranges are: width 2–4 m; length 7–15 m; and height 3–6 m, including space needed for maintenance. This equipment always requires indoor installation.

Dewatering result

The dewatering result of chamber filter presses mainly depends on the characteristics of the sludge and its conditioning. With organic flocculant aids, the dewatering results are similar to centrifuges.

With the chamber filter press, it is possible to use milk of lime (15–25 kg/m^3) and iron chloride (5–12 kg/m^3) for conditioning. In this case, filter cloths with permeability are needed, the air has to be cleaned by an acid washer, and hydrochloric acid is needed for cleaning the filter cloths at certain intervals (e.g. every two weeks). With lime dewatering, results of over 40 % DS are possible; however, in this case, there is 30–50 % of lime inside. Milk of lime has a hygienisation effect, which enables the use of sludge in agriculture in certain countries (see section 6.3). The dewatering result also depends on the type and characteristics of the sludge: with lime/iron conditioning, the dewatering result can be increased up to 45 % DS with primary and a mixture of primary and excess sludge; 35 % DS with aerobically stabilised sludge; and 40 % DS with digested sludge.

Suitability for different types of sludges, and different types and sizes of operation

Chamber filter press dewatering can be applied for primary or excess sludges, possibly after thickening and digestion, and with different types of waste water treatment processes. It is particularly good in handling inorganic suspended solids and chemical sludges.

This technique is used for dewatering sludges at municipality waste water treatment plants mainly in Germany. More often, a chamber filter press is used, for example, in the mining or other industries where the share of inorganic material in sludge is high. For this reason, this dewatering technology is suitable for sludges that contain a significant amount of sludge from chemical precipitation of phosphorus.

Operation, maintenance, environmental and safety aspects

The operation of a chamber filter press usually takes place during one or two shifts a day (8 or 16 hours per day; 5 days per week). This technology requires frequent cleaning according to the instructions of the supplier, and somewhat more maintenance and cleaning work than centrifuges and belt filter presses.

There are no particular environmental concerns with this type of equipment. As ammoniac is produced when using lime, treatment of the air is recommended.

Costs, unit consumptions and manpower

The polymer consumption with chamber filter press is comparable with a centrifuge or a belt filter press, the energy consumption is between both. A chamber filter press has relatively high investment and operating costs compared to centrifuges or belt filter presses due to higher investment and personnel costs.

Investment costs usually range from EUR 150 000 to EUR 350 000 depending on the capacity and construction materials. The technical lifetime of the equipment is usually 15–20 years, although filter cloths and other wearing parts have to be replaced several times during the total lifetime.

The installed power is approximately 20–50 kW and the electrical power consumption of this unit process depends on the actual operating time of the equipment (approximately 20–30 kWh/t DS). Chemical consumption is typically 4–12 kg flocculant aid per tonne of DS. The personnel costs of this dewatering device are high. This unit process needs manpower for cleaning and control; also special operator training by the equipment supplier is required.

Membrane filter press

An improved version of the chamber filter press is the membrane filter press, which reaches a DS content that is 2–3 % higher due to an additional membrane between the filter cloth and the filter plate. With the help of this membrane, the dewatering time can be reduced and the dry solid concentration increased. The investment cost for such a membrane press is much higher; also, as the plates are larger, fewer can be used in one press and thus less sludge can be dewatered.

Figure 5-7: Chamber filter press in Lübeck, Germany. Photo: Entsorgungsbetriebe Lübeck.

5.5 HYDRAULIC PRESS

Operating principles, performance results and space requirements

The hydraulic press belongs to the innovative solutions of sludge handling and it can be considered to be worth considering for municipal sludge dewatering, especially in special cases where the dewatering properties are poor and/or high dry solids content is needed. The hydraulic press application was developed for the solid-liquid separation of biological substances. There are several installations of one supplier in Germany, Austria and Switzerland, and one installation in the Baltic Sea Region, the Käppala waste water treatment plant in Stockholm.

The hydraulic press is designed as a rotating cylinder-piston system with hydraulic drive. Between the bottom of the cylinder and the piston, there are flexible drainage elements which allow the filtrate to drain out of the press interior. The pressing process consists of the following steps: sludge feeding, dewatering by a cyclic press and bulking loops, and the discharge of the filter cake. A complete press process usually lasts 70–120 minutes, depending on the dewatering capability of the sludge. Continuous operation consists of several impulse filling cycles. The dewatering steps are repeated until the required dewatering is reached. The dry solids content of the dewatered sludge usually ranges from 25 % to 40 %. The capacities of these presses vary from 130 kgDS/h to 500 kgDS/h. Space requirements depend on the capacity; typical ranges are: width 2–4 m; length 7–10 m; and height 3–6 m, including space needed for maintenance. This equipment always requires indoor installation. (Bucher Unipektin AG, 2011)

> Innovative methods:
> With the KEMICOND treatment, the hydraulic press reaches up to 50 % DS in the waste water treatment plant in Stockholm. The treatment is explained in section 6.3. Even though this procedure is performed with the hydraulic press, it would be possible with all other dewatering devices as well.

Suitability for different types of sludges and different type and size of operation

Hydraulic presses are usually used for digested sludge, but it is also possible to dewater other sludge types with this equipment. The suitable dry solid content of a suspension to be treated vary between 2 and 10 % DS. This type of equipment is much more expensive than belt filter presses or centrifuges and therefore usually suitable mainly for large wastewater treatment plants.

Operation, maintenance, environmental and safety aspects

The hydraulic press is fully automatic, but as the device is not fed continuously, a buffer is required. Operation can be automatic in 24/7 but also during one or two shifts (8 or 16 hours per day; 5 days per week). This technology requires frequent cleaning according to the instructions of the supplier, and somewhat more maintenance and cleaning work than the previously described dewatering technologies. There are no particular environmental concerns or safety problems with this type of equipment.

Costs, unit consumptions and manpower

Investment costs range usually from EUR 180 000 to EUR 400 000 depending on the capacity and construction materials. The technical lifetime of the equipment is usually 15–20 years, although sieve plates and other wearing parts have to be replaced a few times during the total lifetime.

The installed power is approximately 20–50 kW and the electrical power consumption of this unit process is not very big compared to the overall consumption of waste water treatment (20–30 kWh/t DS). It also depends on the actual operating time of the equipment. Chemical consumption is typically 5–12 kg flocculant aid per tonne of DS. This unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant; however, special operator training by the equipment supplier is required.

Figure 5-8: Hydraulic presses . Photos: Company Bucher Unipektin AG, Switzerland.

5.6 EXAMPLE: PURE partner sludge handling solutions – JURMALA, PIU Jurmalas Udens, Sloka waste water treatment plant

The waste water treatment plant in Jurmala, Latvia, has a total capacity of about 37 500 population equivalents. Some 1 000 tonnes (dry solids, DS) of sewage sludge have to be disposed of annually. The treatment plant is equipped with nitrogen removal and biological phosphorus removal. Within the PURE project, investments, such as measuring equipment to improve the process control, have been made to balance the phosphorus and nitrogen removal performance.

There is no digestion at the waste water treatment plant in Jurmala. As a primary sedimentation does not exist, all the sludge is classified as excess sludge, which is thickened mechanically. One drum thickener is increasing the dry solid content up to 4–7 % with a polymer consumption of 3.5 g/kg DS (grams per kilogram of dry solids).

After thickening, the sludge is dewatered with a dewatering centrifuge that reduces the water content to a minimum, resulting to a DS content of 18 %. The consumption of polymer is about 5.4 g/kg DS. Composting and disposal is outsourced to an external company. There are no problems with heavy metal limits to date. Jurmala Water plans to develop an optimal solution for sludge volume reduction, disposal and reuse which, in turn, will eliminate transportation and storage costs for the part that goes to composting to an external company.

Figure 5-9: Centrifuge and drum thickener, waste water treatment plant Jurmala. Photos: PIU Jurmalas Udens.

Figure 5-10: Sloka waste water treatment plant in Jurmala. Photo: PIU Jurmalas Udens.

5.7 SUMMARY OF THE MAIN DEWATERING METHODS

Questions concerning sludge disposal are often directly connected with sludge dewatering. Costs for transport, disposal and possible drying are all directly dependent on sludge dewatering. The maximum efficiency and dry solid content can reduce costs. For this reason, it is recommended to calculate the dewatering result, energy costs and chemical costs in detail and to consider this in the decision-making and tendering processes. Pilot tests for each possibility should be organised to enable better calculation. The different methods and their suitability for different kind of plants are summarised in Table 5-1. A comparison of PURE partner plants is made in Table 5-2.

Good to know:
Pilot tests should be carried out with equal conditions (temperature, pH, digestion rate etc.), similar to the future operation. Construction work at the plant should be avoided during the tests.

Table 5-1: Overview on dewatering methods and their use in the Baltic Sea region. DS = dry solids.

	Centrifuge	Belt filter press	Chamber filter press		Hydraulic press
			Polymer conditioning	Lime conditioning	
Dewatering result: - aerobically stabilised - digested sludge	 18–24 % 22–30 %	 15–22 % 20–28 %	 18–24 % 22–30 %	 28–35 % 30–40 %	20–35 % 1 - -
Flocculant aid consumption	4–14 g/kg DS	4–12 g/kg DS	5–12 g/kg DS	Lime 15–25 kg/m³ and iron	5–12 g/kg DS
Energy consumption	High	Low	Medium	Medium	Medium
Automatic and continuous	Yes / Yes	Yes / Yes	No / No	No / No	Yes / No
Investment costs	Medium	Medium	Very high	Very high	Very high
Applications	Large, medium-size, small plants (mobile unit)	Large, medium-size, small plants (mobile unit)	Large plants	Large plants	Large plants
Examples of use in the Baltic sea region	FI (Helsinki, Tampere), EE (Tallinn, Kohtla-Järve), RU (St. Petersburg), LV (Riga, Jurmala), DE (Hamburg), PL (Warsaw, Gdansk, Szczecin)	EE (Tarto, Viljandi), FI (Pälkäne), PL (Szczecin-Pomozany), DE (Lüneburg)	Some plants in Northern Germany	DE (Kiel, Lübeck)	SE (Stockholm Käppala)

1 No data for different sludge types available.

Table 5-2: PURE partner comparison of digestion and dewatering. BioP = biological phosphorus removal; DS = dry solids.

PURE Partner	Sludge type	Dewatering device	BioP	DS	Flocculation aid consumption
Kohtla-Järve	No digestion	Centrifuge	Yes	22 %	8 g/kg DS
Riga	Digested sludge	Centrifuge	Yes	19 %	8 g/kg DS
Jurmala	No digestion	Centrifuge	Yes	18 %	5.4 g/kg DS
Gdansk	Digested sludge	Centrifuge	Yes	19.7 %	11.4 g/kg DS
Szczecin Pomorzany	Digested sludge	Centrifuge	Yes	20 %	8–12 g/kg DS
Szczecin Zdroje	Digested sludge	Belt filter press	Yes	19 %	5.3 g/kg DS
Lübeck ZKW	Digested sludge	Chamber filter press	No	37 %	500 g/kg DS (lime)

Photo: HSY Water.

6.1 INTRODUCTION

Municipal sewage sludge hygienisation or disinfection is a procedure to reduce the content of pathogenic bacteria in the sludge below a certain level, which is accepted by the competent authorities. The need for hygienisation depends on the sludge disposal method and is important for agricultural disposal and for disposal to landscaping. Guidelines have been issued by the WHO, as well as German and Swedish authorities although parts are only available in German and Swedish (SNV, 2003, Umweltbundesamt, 2009 and WHO, 2003).

Hygienisation can usually be achieved with two different types of treatments:

- elevation of sludge temperature above 55–70 °C for a certain period of time; and
- elevation of the pH value of the sludge above 12 for a certain period of time.

During the treatment, the bacteria should be eliminated and verified with the relevant measurements. The principles of sludge hygienisation are presented in Figure 6-1.

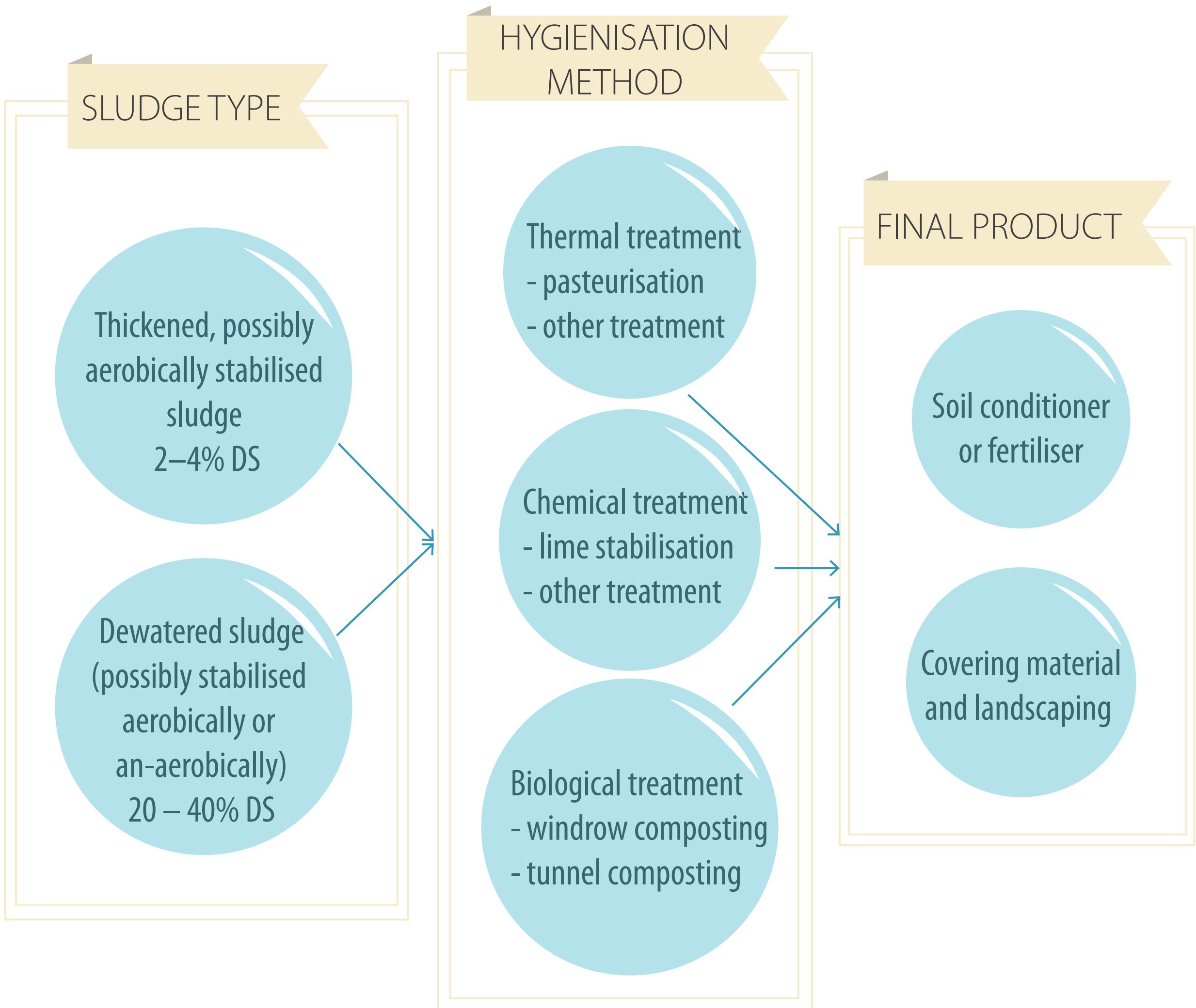


Figure 6-1: Sludge hygienisation.

6.2 THERMAL TREATMENT

In thermal disinfection, the temperature of the sludge is raised to a level at which the bacteria are destroyed. Thermal hygienisation is recommended and sometimes required if animal remains and slaughterhouse waste are treated in the digester together with the municipal sewage sludge.

There are several methods that provide high temperatures for hygienisation:

- (pre-)pasteurisation;
- thermal conditioning;
- drying;
- anaerobic thermophilic stabilisation;
- aerobic thermophilic stabilisation;
- aerobic thermophilic pre-treatment; and
- composting.

6.2.1 Pasteurisation

Pasteurisation is the most commonly used method for thermal hygienisation. It was developed by Louis Pasteur who established this method in the 1860s. It is commonly used for food preservation. In waste water treatment plants, this method is used as follows.

Primary and excess sludge are heated in a hygienisation tank to a temperature of more than 65 °C but less than 100 °C. The retention time has to be 30 minutes at 65 °C, 25 minutes at 70 °C and 10 minutes at 80 °C.

The legal framework of each country specifies the conditions for the pasteurisation: the treatment temperature as well as the retention time is determined. Pasteurisation must take place before digestion so that the pathogenic bacteria are destroyed. Components of these bacteria will then be used in digestion and a reinfection can be excluded. Pasteurisation after digestion would serve as a nutrient medium for reinfection with pathogenic bacteria. (UBA, 2009)

Good to know:
The energy consumption of pasteurisation is very high. Good thickening reduces costs since it decreases the amount of sludge that has to be heated. It is also possible to reduce the energy consumption with a heat exchanger: feed sludge is heated up by cooling down the outlet to digestion temperature. The overall heat consumption of pasteurisation is estimated at 11.9 kWh/m³, the heat losses of the reactor are not included (UBA, 2009).

Figure 6-2: Pasteurisation plant in Kohtla-Järve, Estonia. Photo: OÜ Järve Biopuhastus

6.2.2 Other thermal treatments

- Thermal conditioning means a short increase of sludge temperature in a separate reaction tank before digestion to increase gas production and to disintegrate sludge. One example of this is thermal hydrolysis. This method is usually used for excess sludge. Treating primary and excess sludges together increases heat consumption.
- Drying (see chapter 7) also means increasing the temperature over a certain level; this method provides a hygienisation effect as well. The heat consumption is much higher than with pasteurisation, but the volume reduction reduces disposal costs. Drying is typically used as pre-treatment for incineration (see chapter 8).

Figure 6-3. Photo: Shutterstock.com/Peter Gudella

Good to know:
Aerobic thermophilic pre-treatment can be an option for overloaded digesters.

Good to know:
Temperatures above 180 °C can induce reactions which may result in toxic end-products. In the dewatering process, the toxic chemicals are transferred back to the waste water treatment plant (reject water) and result in operation problems and affect the final effluent. It is also possible that high temperatures result in odour emissions.

- Anaerobic thermophilic stabilisation is explained in chapter 4, and has no practical use in the Baltic Sea Region. It is possible that this technique will be used in coming years, for example in biowaste treatment plants, depending on demands by the regulatory authorities.
- Aerobic thermophilic pre-treatment and stabilisation is too energy intensive and therefore not used yet.
- In composting, the temperature also rises over the needed level for hygienisation. Composting is presented in section 6.4.

6.3 CHEMICAL TREATMENT

The hygienisation of sludge can be achieved with the help of calcium chemicals (CaO or $Ca(OH)_2$) by increasing and maintaining the pH value of sludge at a level of about 12 for as long as biological activity ceases. The minimum time for hygienisation is 2 hours. The dosing is usually regulated by measuring the pH value, and the consumption of lime depends on the hardness and other chemical properties of waste water.

Suitability for different types of sludges and performance results

Milk of lime ($Ca(OH)_2$) is typically fed to non-thickened sludge with a low DS content; for conditioning, it is fed to sludge before dewatering with a chamber filter press (see section 5.4). Burnt lime (CaO) is usually fed to dewatered sludge.

After treatment with lime, there is usually no need to decrease the pH; and after dewatering with any of the technologies presented in chapter 5, sludge can be used in agriculture or in landscaping roads, railways or parks. This is because the pH value of soil usually is too low and therefore alkaline compounds are often spread to cultivated soils to improve their growth properties.

Space requirements, operation and maintenance, environmental and safety aspects

Space requirements of the lime treatment depend on the capacity; typical ranges are: width of 3–4 m; length 5–10 m; and height of 3–6 m, including space needed for maintenance. This equipment always requires indoor installation.

Operation and maintenance of this treatment is relatively simple: chemical dosing equipment and a storage silo is needed together with a mixing unit for the sludge and chemicals.

The following need to be taken into account when using lime for hygienisation:

- the total sludge amount increases and thus the disposal costs increase;
- pH value increases – lime-treated sludge is of good quality for agriculture;
- an acid washer may be required for air emissions of ammonia;
- chemical safety is important because of the high alkalinity; and
- the needed chemical dosing is up to 300–400 kg per tonne of DS.

See some special aspects in section 6.3.4.

Good to know:
Depending on the national regulations, the measurements of the contaminant limits of sewage sludge may occur after lime addition. Lime may dilute the sludge, but also contaminate it. The quality of lime has to be controlled.

6.3.1 Hygienisation with milk of lime

Usually, sludge with a low DS content (2–4 %) is treated with milk of lime (5–10 % $Ca(OH)_2$) which increases the pH value; however, as the reaction is not exothermic, the temperature will not rise with this treatment. Hydrated lime $Ca(OH)_2$ is dissolved with water to milk of lime and then mixed with the sludge in a separate mixing unit before thickening and stabilisation. The mixing unit for hydrated lime and sludge with low DS content is an open tank equipped with a vertical mixer.

In small and medium-size waste water treatment plants without a dewatering unit, it is possible to achieve disinfection by adding milk of lime (to stabilised aerobic/anaerobic sludge), store the sludge for some time after mixing and then use it in agriculture.

6.3.2 Conditioning with milk of lime and iron

Milk of lime and iron can be used for dewatering as flocculant aid with chamber filter presses (see section 5.4). The chamber filter press needs in this case special filter clothes. After dewatering, the sludge has to be stored for some time and can be then used in agriculture. Due to the high price of the chamber filter press, this method is suitable for medium-size and large plants.

The side effects of conditioning are:

- the reject water quality changes and calcium carbonate accumulates in pipes;
- the reject water increases the buffer capacity of the sewage treatment process;
- the reject water treatment is not possible without operation problems;
- the calcium / sodium balance is better, less bulking sludge; and
- a possible blocking of the aeration elements.

Figure 6-4: Sewage sludge, conditioned with milk of lime and then dewatered. Photos: Entsorgungsbetriebe Lübeck.

6.3.3 Treatment with burnt lime

Stabilisation with calcium oxide is usually applied on sludge with high (20–40 %, i.e. dewatered) DS content. Dry lime powder is mixed with dewatered sludge in a closed mixer for only 15–20 minutes due to the rapid temperature increase. When the CaO is mixed with dewatered sludge, the pH value will increase above 12. The CaO will then react with the water and, in this exothermic reaction, the temperature will rise typically above 60 °C, part of the water will evaporate and the dry solids content will increase somewhat.

Burnt lime can be used at every waste water treatment plant with a dewatering unit (see chapter 5). Due to the exothermic reaction and the high temperature, treatment with burnt lime has a better hygienisation effect than the treatment with milk of lime.

The mixing unit for burnt lime and sludge with high DS content is a closed system, including a horizontal blade mixer, for instance.

Costs, unit consumptions and manpower

The investment cost of lime treatment is about EUR 200 000 to EUR 400 000 depending on the capacity. The technical lifetime of the equipment is usually 15–20 years. The chemical consumption of this unit process is the main contributor to the operating costs and can be up to 300–400 kg CaO /t DS. The minimum consumption is on a case-by-case basis depending on the type and dry solid content of the sludge, and can be determined experimentally to meet the requirement minimum 2 h at pH > 12. Chemical costs depend on the unit cost of lime, which vary depending on the volume and country. Using the specific consumptions mentioned above, the chemical costs are about EUR 20 to EUR 40 /t DS. The installed power is approximately 10–20 kW and the electrical power consumption of this unit process is approximately 7–15 kWh/t DS. This is marginal compared to the overall consumption of waste water treatment.

This unit process does not require any additional manpower or special competences beyond the normal operation of the waste water treatment plant. Conditioning with milk of lime and iron involves the use of a chamber filter press, the costs of which are discussed in section 5.4.

Use in the Baltic Sea Region

In the Baltic Sea Region, lime treatment is seldom used. Some examples from Finland are Iisalmi Water that uses lime stabilisation at the Vuohiniemi treatment plant for the dewatered sludge and Savonlinna Water. In the Baltic Sea region, milk of lime and iron conditioning is used in Lübeck and Kiel, in Germany. The waste water treatment plant in Szczecin has the possibility to use lime for agricultural use, but does not do so.

6.3.4 Other chemicals

There are different possibilities to treat sludge with chemicals other than lime. Typically, chemicals that increase the pH value are used. The whole amount of sludge should always be treated. It is essential that the used hygienisation method is applied according to the relevant legislation.

Kemicond treatment can be applied to treat thickened primary and excess sludge. Usually, the main objective of stabilisation with the Kemicond treatment is the hygienisation of sludge, and it has been observed to improve the sludge dewatering properties as well. The treatment is carried out in a separate mixing tank by reducing the pH value to about 4 by using sulphuric acid (H_2SO_4). In acidic conditions, the gel-type structure of the sludge will be disintegrated and metal salts like ferrophosphate ($Fe_3(PO_4)_2$) or ferrous oxides (FeO) will be dissolved. After this stage, the sludge is oxidised with hydrogen peroxide (H_2O_2), and iron ions will be converted from Fe^{2+} to Fe^{3+}. The latter form of iron will precipitate phosphates as ferric phosphates ($FePO_4$).

In oxidising conditions, the gel-type structure of the sludge will be further disintegrated. At dewatering after Kemicond, it is possible to release more water out of the sludge. Finally, the chemical treatment is completed by neutralising the sludge with sodium hydroxide (NaOH) before polymers are added to enhance sludge dewatering.

During the treatment, sludge is hygienised with the highly oxidising hydrogen peroxide treatment – it is nearly odour-free as well as easy to store and transport. Possible national restrictions may exist concerning the use of this kind of technology and the available methods of disposal (agriculture, landscaping directly or after composting, which is recommended by the supplier).

Space requirements mainly depend on the capacity. Dosing and mixing units as well as storage silos are needed. Typically, the size of the equipment: is width 4–6 m; length 8–10; and height 4–6 m. Chemical safety is important because acids, bases and oxidants are used. The operational costs (chemicals) are high. Typical consumptions are about 220 kg H_2SO_4 per tonne of DS and 27 kg H_2O_2 per tonne of DS. Due to high costs, this procedure is only suitable for large plants.

Costs, unit consumptions and manpower

The investment cost of this technology is about EUR 400 000 to EUR 700 000 depending on the capacity. The investment costs can be somewhat reduced by outsourcing the whole operation and disposal of the treated product to an external contractor. The technical lifetime of the equipment is usually 15–20 years. Chemical costs depend on the unit cost of sulphuric acid and hydrogen peroxide, which vary depending on the order volume, and from country to country. The sulphuric acid consumption is about 220 kg H_2SO_4 /t DS and hydrogen peroxide consumption about 27 kg H_2O_2 /t DS. With these chemical consumptions, the chemical costs are about EUR 50 to EUR 60 /t DS. The installed power is approximately 15–25 kW and the electrical power consumption of this unit process is approximately 10–20 kWh/t DS. This is quite small compared to the overall consumption of waste water treatment. It also depends on the actual operating time of the equipment. The chemical consumption of this unit process is the main contributor to the operating costs, but should be investigated case-by-case with laboratory and pilot tests.

This unit process does not need any additional manpower, but it may require additional competences for chemical safety issues beyond the normal operation of the waste water treatment plant.

> Innovative methods:
> Hygienisation is only a side aspect of the Kemicond treatment. This treatment improves the dewatering results. In Stockholm, 50 % DS is reached with the Kemicond treatment combined with hydraulic press dewatering; in different wastewater treatment plants, a DS of between 38 % and 45 % has been reached with the chamber filter press and Kemicond (Brendler, 2006). Also, the use of centrifuges and belt filter presses are possible with this method.

Figure 6-5. Photo: Jannica Haldin, HELCOM

Use in the Baltic Sea Region

This technology is used only in a few cases in the Baltic Sea Region. Stockholm's Käppala waste water treatment plant in Sweden and the Oulu waste water treatment plant in Finland (example of outsourcing) are among these few cases.

6.4 BIOLOGICAL TREATMENT

6.4.1 Operating principles and suitability for different types of sludges

Composting is an aerobic bacterial decomposition process to stabilise organic wastes and produce humus (compost). Composting is a simple and proven technology to achieve hygienisation (60 °C for 3–6 days) and to produce useful products like compost and fertilizers. The national legislation should be taken into account since in some countries, the required composting time can be significantly longer than six days.

The selection of composting technology is driven by the following criteria:

- low costs both for capital investment and for operation; and
- simple technology, which could be reliably operated by the sludge handling operators without extensive training.

For composting sludge, its dry solids content should be increased to at least 15 % DS so that it can be handled as a solid. Thickening and dewatering (see chapters 3 and 5) primary and excess sludges are required to achieve this dry solids content. This method can also be used for anaerobically stabilised (digested) and thereafter dewatered sludge. Mixing with bedding materials, such as dry sawdust, may assist in achieving the required solids content as well as attaining the required carbon to nitrogen ratio for composting.

Composting technologies available in the Baltic Sea Region range from simple open windrow systems with a small effort in terms of process structures to fully enclosed composting plants with accelerated treatment processes, complete enclosure and a high quality treatment of exhaust air. The various technologies are largely proven and well understood in their capabilities and limitations. The most feasible for sludge handling are windrow composting and tunnel composting technologies. The operation and maintenance of both methods are relatively simple and only require a basic understanding of the biology and biochemistry of composting.

6.4.2 Windrow composting

Operation, maintenance, environmental and safety aspects

Composting using the windrow method requires some management to set up windrow piles, turning them periodically, and monitoring the temperature and other key parameters of the composting process. Sometimes, additives and seed microbes are proposed to be used to ensure proper operation of the composting process; however, many operators are confident that no special additives are required when part of the sludge is recycled with the bedding material. The windrows do not usually require a membrane or other covering material.

Windrow composting occurs outdoors on asphalted or otherwise coated areas with low permeability to the soil where the windrows are located, and where there is enough space for turning and storing during the maturation stage. The windrows are formed by mixing the sludge and the bedding material (sawdust, woodchips or topsoil peat) typically using front-end loaders. Normally, 40–50 % by volume of the bedding material is mixed with the composted sludge and the bedding material is separated from the composted sludge and recycled back to use. Since this method requires a moist environment and the presence of oxygen, the composted sludge must be aerated by turning the piles once every two to four weeks.

The machinery used in turning the windrows is a key component to produce good quality compost, as well as one of the major sources of investment and operating costs. The machinery for windrow turning includes front-end loaders, rotating drums, screening equipment for the bedding material, as well as conveyors and augers, depending on the local conditions for feeding and unloading the materials. While farm equipment has been used for compost turning as early as the 1930s, specialised compost turning equipment for large-scale applications became available in the 1970s, and has been developed extensively since the beginning of 1990s.

Typical space requirements mainly depend on the amount of sewage sludge. The space requirement is high compared with other hygienisation methods and can be 50–100 m by 150–200 m, including on-site storage for the composting material.

Windrow composting can be applied in small and medium-size plants. It is also possible to apply this method at a large waste water treatment plant if enough space is available.

Costs, unit consumptions and manpower

The investment costs usually range from EUR 500 000 to EUR 3 million depending on the capacity of the turning machines and the size and materials of the composting area. The investment costs can be somewhat reduced by outsourcing the turning of composting to external contractors or significantly reduced by outsourcing the whole operation and disposal of the compost product. The technical lifetime of the equipment is usually 10–15 years. Recyclable compost support material, such as wood chips (originating e.g. from construction and demolition waste), is needed to keep the compost in an aerobic condition. Wood chips are usually recirculated by screening the final compost material; a small amount of new wood chips are added to compensate a minor decrease of this material over time. The costs of the additional material are less than EUR 10 /t DS.

This process does not necessarily require electrical power or chemicals since it is operated with mobile equipment using diesel oil. This unit process does not need additional manpower – despite the turning of the piles – or special competences beyond the normal operation of the waste water treatment plant.

Good to know:

There are no particular environmental concerns with this type of technology in normal operation. Only in case of insufficient turning or moistening of the material, the windrows may start to operate in anaerobic conditions and cause air emissions of malodorous gases containing hydrogen sulphide.

Figure 6-6: Composting of waste water sludge in Helsinki, Finland and Kohtla-Järve, Estonia.
Photos: HSY Water and OÜ Järve Biopuhastus.

Use in the Baltic Sea Region

This composting technology is extensively used in the Baltic Sea Region. It is applied at urban municipalities up to 1 000 000 population equivalents, such as in the Helsinki Metropolitan Region in Finland; in medium-size cities like Kohtla-Järve and Viljandi in Estonia; Jurmala in Latvia; and Oulu in Finland, as well as at plants in Denmark, Germany (e.g. Siebenhitz), Lithuania, Poland and Sweden (e.g. Uppsala, Vännersborg, Borås and Sofiedal). Windrow composting is also becoming more common in Russia.

6.4.3 Tunnel composting

Operation, maintenance, environmental and safety aspects

Tunnel composting is carried out as a batch process in a series of tunnels that are filled with front-loaders or with more sophisticated automatic systems such as conveyors. The current development has been going towards less sophisticated systems and investing mainly in the mixing area, tunnel structures made of concrete and the ventilation systems for their aeration. The tunnels are typically 4–6 m wide, 6 m high and 20–40 m long with common intermediate walls between two neighbouring tunnels; the building is usually 20–25 m wide, 6 m high and 20–40 m long. After the intensive composting stage in the tunnels, the sludge is often maturated and stabilised in windrows with a space requirement of approximately 50–60 m by 80–100 m. Tunnel composting is an old and proven technology and can be applied in medium-size and large biological waste water treatment plants.

At larger composting sites (500 000–1 000 000 population equivalents) with high capacity demand, tunnel composting may be feasible to reduce the residence time of the waste water sludge down to 10–15 days in the composting process. The key operation features are:

- Accelerated turning rates by operating and moni toring the performance of each tunnel.
- Forced aeration by negative pressure to avoid uncontrolled air emissions. This could be applied by simple aeration channels in the floors. Blowers collect air from these channels forcing the outside air to pass through the sludge and accelerating the composting process.
- Exhaust air treatment. The collected air is both very odorous and contaminated with ammonia. As a minimum treatment, it passes an acid scrubber and preferably an additional biofilter.

Good to know:

As with windrow composting, in case of insufficient turning or excessive moistening of the material, composting tunnels may start to operate in anaerobic conditions and cause emissions of malodorous gases containing hydrogen sulphide.

Costs, unit consumptions and manpower

Investment costs usually range from EUR 1.5 million to EUR 5 million depending on the capacity and the size and materials of the composting buildings. Also, with this technology as with windrow composting – if mobile front-loaders are used for mixing the materials and filling and emptying the tunnels – external contractors are used to minimise the amount of the capital investment and labour costs of the permanent personnel. The technical lifetime of the equipment is usually 15–20 years.

The installed power can vary between 75 and 120 kW due to the ventilation of the composting chambers; the electrical power consumption of this unit process can be significant compared to the overall consumption of waste water treatment, approximately 100–200 kWh/t DS. It also depends on the actual operating time of the equipment. Usually, no chemicals are needed for tunnel composting. Despite filling and emptying the tunnels, this unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

Many tunnel composting plants handle a mixture of wastewater sludge, source-separated municipal biowaste and green waste from gardens.

Use in the Baltic Sea Region

Composting technology is used quite widely in some countries in the Baltic Sea Region; to date, however, it is seldom if at all used in Poland, Germany, Estonia, Latvia or Lithuania. In Russia or Belarus tunnel composting is not practised at all. In Finland, tunnel composting is in operation in Jyväskylä, Varkaus, Lahti, Rovaniemi, Espoo (tunnel composting located at Nurmijärvi), Joutseno, Kitee, Himanka and Mäntsälä. In Denmark and Sweden, there are several tunnel composting plants in densely populated areas.

6.5 EXAMPLE: PURE partner sludge handling solutions – KOHTLA-JÄRVE, OÜ Järve Biopuhastus, Kohtla-Järve waste water treatment plant

The waste water treatment plant in Kohtla-Järve (Estonia) has a total capacity of 200 000 population equivalents. Nearly 2 700 tonnes of sewage sludge (dry solids, DS) is generated annually. The plant has nitrogen removal and chemical and biological phosphorus removal.

There is no primary sedimentation at Kohtla-Järve waste water treatment plant so the total sludge is produced as excess sludge. The excess sludge is thickened mechanically to approximately 6 % DS. The polymer consumption is about 4 g/kg DS.

The sludge is treated after mechanical thickening in reactors to remove harmful bacteria. The sludge is heated in the process for 20 to 24 hours at 55 °C. After this, the sludge is dewatered in a centrifuge to 22 % DS. The polymer consumption is about 8 g/kg DS. After dewatering, the sludge is mixed with shredded wood material and formed into piles at a composting plant.

The sludge product from the composting plant is used in landscaping. None of the existing heavy metal limits are exceeded. However, due to the high amount of industrial sewage in Kohtla-Järve, the operator cannot sell compost on the market, but it is delivered free of charge.

Figure 6-7: Kohtla-Järve waste water treatment plant. Photo: OÜ Järve Biopuhastus.

Currently, the plant does not have an anaerobic digestion and therefore no own energy production; the energy balance is negative. In the near future, a digester will be built to produce energy and decrease the volume of the sludge.

Figure 6-8: Composting of waste water sludge in Kohtla-Järve, Estonia. Photo: OÜ Järve Biopuhastus.

6.6 EXAMPLE: PURE partner sludge handling solutions – HELSINKI, HSY Water, Viikinmäki and Suomenoja treatment plants

Helsinki Metropolitan Area generates over 100 million m^3 of wastewater annually (altogether 1.1 million PE), that is treated in Finland's two largest waste water treatment plants, in Viikinmäki (Helsinki) and Suomenoja (Espoo) by the regional environmental services authority HSY Water. HSY Water is an associated partner of PURE. Annually, 65 000 tonnes of dried sludge is produced in Viikinmäki and 25 000 tonnes in Suomenoja.

Retention time in primary sedimentation is 2.8 h in Viikinmäki and 2.1 h in Suomenoja, and primary sludge solids content 3.6 and 1.3 % (total solids, TS), respectively. In Suomenoja, the primary sludge is thickened before digestion. The concentration of excess sludge in Viikinmäki is 7.5 g/l. The content of solids in the sludge fed to the digesters was on average 4.1 % TS in 2011.

In Viikinmäki, there are four digesters that are run in series – two are primary stage digesters and two are secondary phase digesters. The sludge is not heated before the second phase. In Suomenoja, two digesters are run in parallel. Retention time and feed temperature in the digesters is 17 d at 37 °C in Viikinmäki and 13 d at 35.5 °C in Suomenoja. Dry solids after digestion is 2.3 % TS in Viikinmäki and 2.7 % in Suomenoja.

Dewatering is done by centrifuges (four in Viikinmäki and three in Suomenoja). Solids concentration after dewatering is 29 % TS in both plants. Polymer consumption is 4.5 g/kgTS in Viikinmäki and 6.1 g/kgTS in Suomenoja.

The digested sludge from Viikinmäki is transported to HSY's composting area in Sipoo, east of Helsinki. Peat is added to the sludge and it is composted for 6–9 months in open bioreactors. Sand, minerals and nutrients are added and after screening the product is sold for landscaping and agricultural use. Currently, the market demand is higher than HSY Water actually can produce. The digested sludge from Suomenoja is treated in Nurmijärvi, north of Espoo, where peat and recyclable binding material are added to the sludge and it is tunnel composted for three weeks by an external company. It is used as covering material at HSY's Ämmässuo Waste Treatment Centre landfill. The drainage waters from composting are discharged back to Viikinmäki and Suomenoja treatment plants.

Biogas from digestion is utilised in CHPs at the treatment plants for producing electricity and heat. In 2011 the biogas production was 12.3 million m^3 at Viikinmäki and 3.5 million m^3 at Suomenoja. Heat was produced altogether 27 500 MWh at Viikinmäki from biogas, and 4 100 MWh was gained from heat recovery, altogether over 99 % of consumption. In Suomenoja 9 560 MWh of heat was produced, of which 97 % with biogas. Approximately 25 000 MWh of electicity was produced in Viikinmäki (60 % of consumption) and over 4 500 MWh in Suomenoja (35 % of consumption).

In 2011 an extensive research project was started in Viikinmäki for implementing nitrogen removal for the centrifuge reject waters. Biogas from Suomenoja will be sold from November 2012 on to an external company for refining it to the natural gas network and as a transport fuel.

Figure 6-9. Viikinmäki treatment plant in Helsinki is constructed inside bedrock. Photo: HSY Water.

6.7 SUMMARY OF HYGIENISATION METHODS

The available hygienisation methods have different hygienisation results and side effects thus making the right choice of method somewhat complicated. The price for energy and chemicals varies from country to country and the land availability and price for composting can vary significantly between waste water treatment plants. The different methods and their suitability for different kinds of plants are summarised in Table 6-1. A comparison of PURE partner plants is given in Table 6-2.

Table 6-1: Overview of different hygienisation methods. Depending on regulations and costs (energy, personnel, investment, chemicals) the classification may change (based on UBA, 2009). DS = dry solids, WWTP = waste water treatment plant.

Small WWTP	Medium WWTP	Large WWTP
Thermal treatment		
-	Pasteurisation	Pasteurisation
-	Aerobic thermophilic stabilisation	Aerobic thermophilic pre-treatment
-	-	Thermal conditioning
		Anaerobic thermophilic stabilisation
Drying (solar, see chapter 7)	Drying (solar)	Drying (thermal)
Chemical treatment		
Treatment of sludge of low DS with milk of lime	Treatment of sludge with low DS with milk of lime	
-	Conditioning with milk of lime in chamber filter press	Conditioning with milk of lime in chamber filter press
Use of burnt lime after dewatering (mobile)	Use of burnt lime after dewatering (mobile or stationary)	Use of burnt lime after dewatering
Biological treatment		
Composting in windrows with dewatering technique	Composting in windrows with dewatering technique	Composting in windrows with dewatering technique
-	Composting in tunnels with dewatering technique	Composting in tunnels with dewatering technique

Use in the Baltic Sea Region

The practised hygienisation methods differ between the Baltic Sea Region countries. The most used methods are composting, lime treatment and pasteurisation. In Finland and Estonia, composting is state-of-the-art, while in Germany lime treatment is common. Some methods are not applied in the Baltic Sea Region, like solar drying and drying for agricultural use, aerobic thermophilic stabilisation and pre-treatment, and anaerobic thermophilic stabilisation. Thermal conditioning is used but seldom for hygienisation, because the energy demand is much higher when primary sludge is also treated. Among the PURE partners, hygienisation is in use in Kohtla-Järve, Estonia, and Lübeck, Germany.

Table 6-2: Comparison of the most common hygienisation methods in the Baltic Sea Region.

	Composting	Lime treatment	Pasteurisation
Investment costs	High	Low-medium	Medium
Energy demand	Low	Low	High
Chemicals demand	No	Yes	No
Structure material needed	Yes	No	No
Sludge dewatering needed	Yes	No	No
Space needed	High	Low	Low
Hygienisation result	Medium – good	Medium/Good	Very good

7. SLUDGE DRYING

Mussels and pondweed on gravel. Photo: Metsähallitus.

7.1 INTRODUCTION

Thermal drying is a technology that aims to significantly reduce the water content of sludge. Drying is mostly used in large waste water treatment plants to increase the heat value of sewage sludge for incineration. Also, drying for agricultural disposal is possible, but not often practised because of its high costs. The removal of water by evaporation from the treated and dewatered sludge increases the dry solids content of the sludge, and reduces both sludge volume and weight. The dry solids content of the dewatered sludge is typically between 20 and 30 % DS. After drying, the solids content is between 50 and 90 %.

The thermal drying process typically includes material handling and intermediate storage; it is preceded with sludge dewatering and sludge silos, and requires heat generation and distribution equipment, a thermal dryer unit, a biological filter for exhaust gases, a post-processing unit like pelletizing, and storage for the final product. The principles of thermal drying are presented in Figure 7-1.

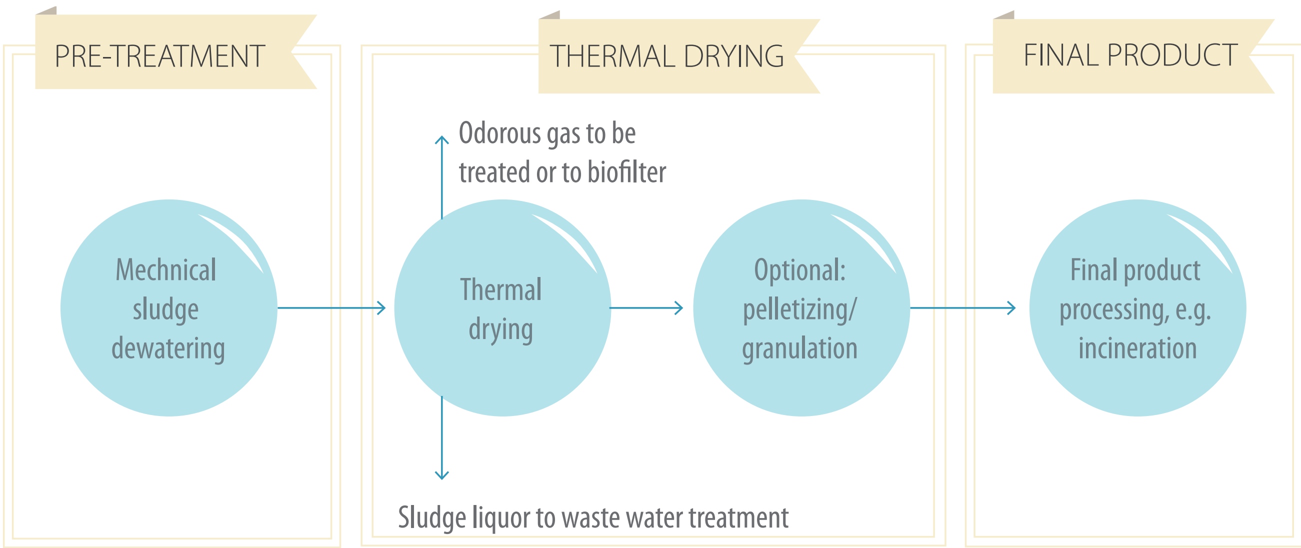


Figure 7-1: Principles of thermal drying.

Innovative methods:
Solar drying is a possibility to dry sludge with very low operational costs. It is not used in the Baltic Sea Region so far. In a few plants in northern Germany (Bredstedt), solar drying is used for sewage sludge. Often, additional heat from the waste water treatment plant, from a biogas plant or from other sources (industry, geothermal energy) is used to support drying, especially in winter. So far, solar drying is used in small and medium-size treatment plants. Due to high costs for external energy like oil and gas, this possibility is becoming more and more attractive also for larger plants. The climate in the northern Baltic Sea region (Finland, northern Sweden, Estonia) is decreasing the efficiency; however, in other countries like Poland, Denmark, Germany, Lithuania, Latvia and southern Sweden, solar drying can be a possible alternative. In countries like Russia, where the gas price is quite low, solar drying is not cost-efficient. Factors like the moisture content of air, snow loads, etc. have to be taken into account; the requirements are similar to greenhouses located in the same region as the waste water treatment plant. Overall, the operational costs are low, but the investment costs are high.

7.2 OPERATING PRINCIPLES AND SLUDGE DRYING METHODS

Thermal drying is based on the use of heat to evaporate water from the sludge after dewatering. The energy input in dewatering is much lower than in drying, thus a high DS content after dewatering is required. Thermal drying processes are divided into two main categories – direct (convection drying) and indirect (contact drying) heating. This classification is based on how the thermal energy is applied to the sludge in order to increase the temperature.

Sludge drying is applied for dewatered (20–30 % DS) primary and/or excess sludges as well as digested sludge after dewatering. Due to the high investment costs, it is usually restricted to large plants.

In **direct drying** of sludge, heat convection is achieved with direct contact with hot air or hot gases. The sludge's temperature is increased and water is evaporated. Typical direct drying equipment is a rotary drum dryer or belt dryer. Temperatures of about 450–460 °C (drum) or 120–160 °C (belt) are applied for about 5–10 minutes (drum) or 40–60 minutes (belt dryer).

A rotary dryer consists of a cylindrical steel shell that is rotated on bearings and usually mounted with its axis on a slight slope from the horizontal. The feed sludge is mixed with previously dried and recirculated sludge in a blender located ahead of the dryer. The feed mixture and hot gases are conveyed to the discharge end of the dryer. During conveyance, axial lights along the rotating interior wall pick up and cascade the sludge through the dryer. The dried sludge is screened and the oversize material passes through a crusher, and the dry material is transferred to a silo or a transportation bin. (Burton et al., 2003).

In **indirect drying**, a solid wall separates the sludge from the heat transfer medium, usually hot water, oil or steam. Typical, indirect drying equipment include vertical tray dryers and horizontal disc, paddle or spiral dryers as well as fluidised bed dryers. Temperatures of about 160–200 °C for steam as the heating medium and 190–240 °C for thermal oil are applied with disc dryer for 45–60 minutes, for example. The product temperature is 85–95 °C during the drying stage and exhaust air temperature is 95–110 °C.

Horizontal dryers are the most common indirect dryers; they employ paddles, hollow flights or discs mounted on one or more rotating shafts to convey the sludge through the dryer. The heated medium, steam, oil or hot water is circulated through the jacketed shell of the dryer and the hollow core of the rotating assembly. The incoming sludge is fed perpendicular to the dryer shaft and passed horizontally in a helical pattern through the dryer. The dryer performs a dual function of heat transfer and conveying the solids. Drying occurs as the sludge is broken up through agitation and comes into contact with the heated metal surfaces in the dryer (Burton et al., 2003). Part of the dried sludge is recirculated inside the dryer to prevent incoming sludge sticking to the hot metal surfaces, which takes place when the dry solids content is between 45–60 % DS.

Figure 7-2: Disk dryer in Gdansk, Poland. Photo: GIWK.

Performance results and the final product

Thermal drying can be either full drying until the dry solids content is over 85 % DS or partial drying until the dry solids content less than 85 % DS. The fully dried product is either a dusty or granulated (or pelletized) product. The dusty product is often fed directly to incineration (see chapter 8), while granulated sludge is much easier to handle. Granulated sludge can be used as fertiliser on agricultural land. The dry solids content of 85–90 % DS is suitable for storage in silos or large bags. For incineration purposes, the dry solids content is dependent on the energy balance and is determined case by case. The minimum dry solids content is 45–60 % DS for mono-incineration without additional fuel. The product is not dusting during transportation and further handling.

Thermally dried material usually fulfils the standard hygienic requirements. Thermal drying also reduces the volume and weight of the waste water treatment sludge. If the sludge's dry solid content is 25 % before drying and 95 % after, the weight is reduced to about 25 % of the original weight.

Thermal drying improves the calorific value of the sludge, in which case it can be utilised more effectively in energy production. Combustion at a DS content of over 50 % is already self-sustaining.

Operation, maintenance, environmental and safety aspects

The operation of this technology usually takes place continuously 24/7, especially if the sludge drying is followed by sludge incineration. Operation and maintenance is somewhat more demanding than other unit operations of sludge handling; however, sludge incineration is technically even more demanding.

Sometimes there can be airborne dust even if the final product is granulated and thus personal protective equipment is required when handling the product. There can also be risks of fire and dust explosion in the process, and thus sections of the plants usually require explosion protection measures. With the fine particles and high levels of dryness of thermally dried sludge, hazards due to fire and explosion may exist in conveying or storing the sludge. Organic airborne dust can rapidly combust if exposed to an ignition source. The main preventive measures to avoid sludge dust hazards are:

- keeping all areas clean from dust;
- providing explosion-relief vents or valves in the ventilation system;
- installing explosion-protected electrical equipment;
- providing an inert nitrogen atmosphere in sludge conveying and storage systems (nitrogen padding);
- electrically bonding and grounding all conductive ducts and vessels.

The main environmental concerns are the dust or odour emissions from drying. The former can be effectively reduced with flue gas filters, while the emissions of malodorous gases can be reduced with gas scrubbers.

Costs, unit consumptions and manpower

The capital and especially the operation costs are relative high for the thermal drying process, mainly due to the high amount of heating energy needed. Therefore, it is preferred to locate the thermal drying plant where low-cost secondary heat generated by a primary energy source, or biogas or landfill gas is available. It is favourable for the process to utilise the excess process heat of anaerobic digestion or waste incineration plants, local district heating network or a greenhouse nearby. From a sustainability point of view, fossil fuels should not be used for drying.

Investment costs of drying equipment and indoor space for it range usually from EUR 500 000 to EUR 2 000 000 depending on the type, capacity and equipment materials. The technical lifetime of the equipment is usually 15–20 years. The installed power can vary between 150–200 kW due to main drives and blowers, etc. and the electrical power consumption of this unit process is approximately 70–100 kWh/t DS depending on the type of equipment. This is relatively high compared to the overall consumption of waste water treatment. It also depends on the actual operating time of the equipment. No chemicals are usually needed for sludge drying. This unit process does not need any additional manpower; however, additional skills and special competences for thermal processes and the maintenance of explosion risk zones are needed beyond the normal operation of the waste water treatment plant.

Figure 7-3: Sludge drying and incineration in Szczecin, Poland. Photo: ZWiK Szczecin.

7.3 EXAMPLE: PURE partner sludge handling solutions – SZCZECIN, Zaklad Wodociagow i Kanalizacji Sp z.o.o. w Szczecinie ZWiK

Pomorzany waste water treatment plant

The city of Szczecin in Poland has two modern waste water treatment plants. Pomorzany is a wastewater treatment plant with a total designed capacity of 418 000 population equivalents and a sludge production of 6 300 (at present 5 000–5 500) tonnes of sludge (dry solids, DS) annually – nearly twice as large as the other waste water treatment plant in Szczecin, Zdroje. The plant has nitrogen removal and both biological and chemical phosphorus removal.

The Pomorzany waste water treatment plant has primary sedimentation with a retention time of 2 hours. The primary sludge is removed with a dry solid content of 2.5 %. It is thickened by gravity thickening to 6 %. Excess sludge is mechanically thickened in a belt filter up to 6 %. The polymer consumption of the belt filter is about 3–5 g/kg DS.

The excess sludge and primary sludge are fed into a mesophilic digester that has a DS content of 3.5 %. The digestion temperature is 37 °C and retention time 20 days. The biogas is utilised in three 350 kW CHPs (combined heat and power plants) that have an electrical efficiency of 37 %. The degree of self-sufficiency is 70 % and gas can be stored for around 25 hours.

Figure 7-4: Digesters and gas tanks, Pomorzany waste water treatment plant, Szczecin, Poland. Photo: ZWiK Szczecin.

The digested sludge is dewatered in a belt filter press to a DS content of about 20 %. The polymer consumption is 8–12 g/kg DS. The dewatered sludge is dried in a belt dryer up to 96 % and then burned in an incineration plant. After incineration, the ash is disposed to landfill.

In the coming years, the optimisation of sludge digestion and dewatering is planned, possibly with disintegration.

Figure 7-5: Pomorzany waste water treatment plant, Szczecin. Photo: ZWiK Szczecin.

Zdroje waste water treatment plant

The waste water treatment plant Zdroje is the smaller of the two sewage treatment plants in Szczecin. The plant is designed for a total of 177 000 population equivalents. The present total sludge production, however, is only 1 680 tonnes (dry solids, DS) per year. Zdroje has biological nitrogen removal and biological as well as chemical phosphorus removal.

Primary sludge is collected in the primary sedimentation tank with a retention time of 1.5 h. Sludge is then thickened to 5 % DS by gravity thickening. The excess sludge is thickened mechanically in drum thickeners to over 5 %. A total of 6.5 g/kg DS of polymer is necessary. The thickened sludge is fed to digestion, operating with a temperature of 30 °C to 35 °C. The solids content is 3.5 %, and retention time 24 days.

The digested sludge is dewatered by centrifuges to a DS content of 19 %. The polymer consumption is about 5.3 g/kg DS. The dewatered sludge is dried to 95 % DS by belt drying. Heat from a CHP is one of the energy sources used for drying. The CHP (one 238 kW unit) has an electrical efficiency factor of 35 %. The plant is able to produce about 40 % of the needed electricity.

The dewatered and dried sludge is burned in the Pomorzany waste water treatment plant's incineration plant. Also, landfilling or agricultural use is possible (the latter after hygienisation with lime).

In the coming years, different tests will show if the dewatering result can be increased, for example with the help of iron salt for dewatering or disintegration.

Figure 7-6: Zdroje waste water treatment plant, Szczecin.
Photo: ZWiK Szczecin.

7.4 SUMMARY OF MAIN THERMAL DRYING METHODS

Table 7-1: Direct heating and indirect heating summary. DS = dry solids.

<table>
<tr><th>Technology</th><th>Features</th><th>Remarks</th></tr>
<tr><td>Direct heating (45 – 90 % DS)</td><td>Sludge is in direct contact with the heat transfer medium. Rotary drum or belt dryers are typical equipment.</td><td rowspan="2">Cost from EUR 0.5 to EUR 2 million. Installed power 150–200 kW.
Consumption of electrical energy 70–100 kWh/t DS.
Secondary heat can be utilised to save in energy costs.
Maintenance of explosion risk zones needed.</td></tr>
<tr><td>Indirect heating (45 – 90 % DS)</td><td>Sludge is not in direct contact with the heat transfer medium; e.g. tray, paddle or fluidised bed drying equipment is used.</td></tr>
</table>

Use in the Baltic Sea Region

Thermal drying is a well-known and a proven technology in central Europe where it has been applied on both large and medium scales. The Baltic Sea Region has operational experience in thermal drying, for example in Copenhagen, Denmark; Hetlingen and Hamburg, Germany; and more recently in Finland (Ekokem, Riihimäki) and Poland (e.g. in Cracow, Gdansk, Łodz, Szczecin). Solar drying is used in Bredstedt (Germany).

8. SLUDGE INCINERATION

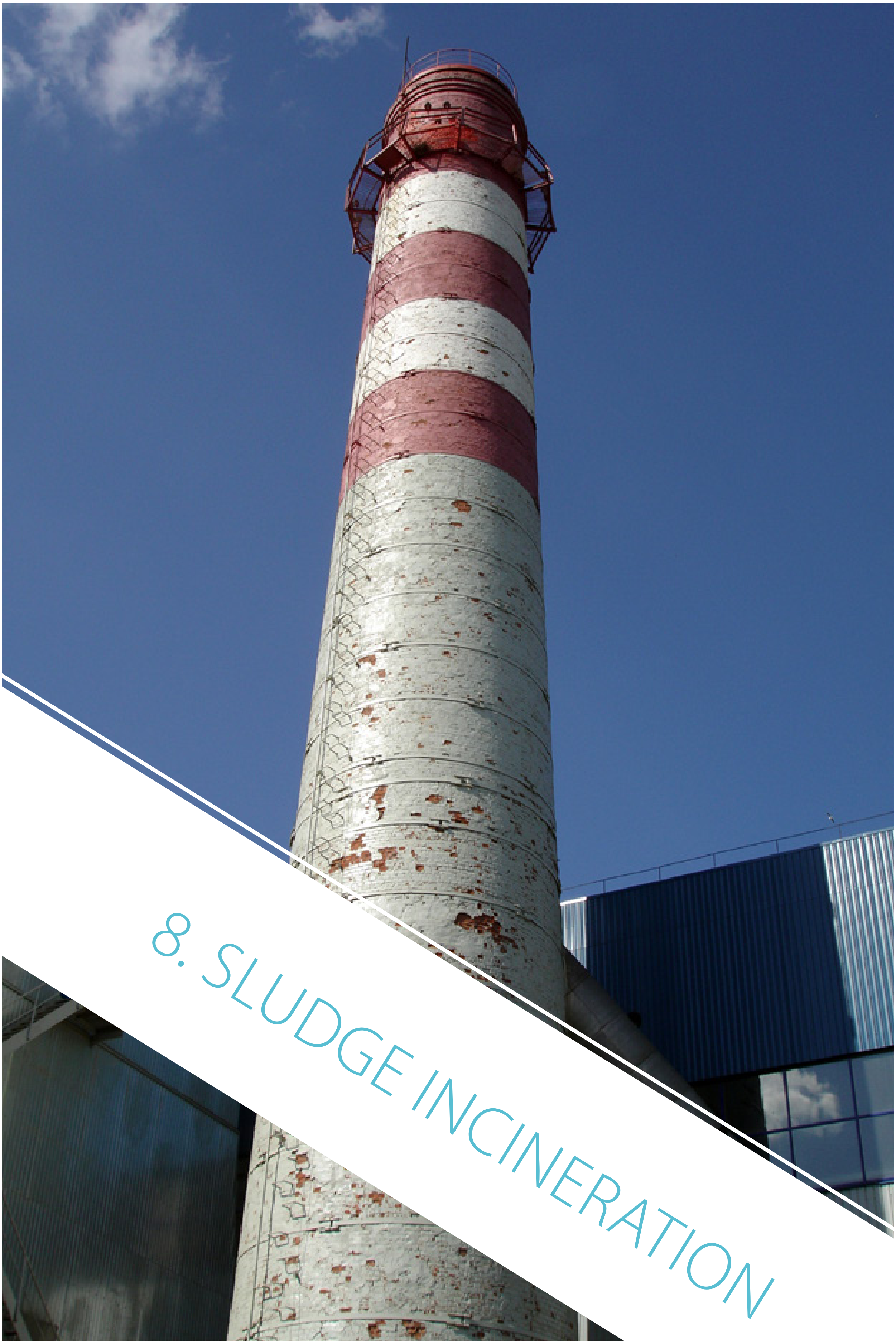


Photo: Lotta Ruokanen, HELCOM.

8.1 INTRODUCTION

Sewage sludge is a good fertiliser because of the high concentrations of phosphorus and nitrogen; however, it can also be a sink for contaminants. In addition to various organic substances, heavy metals may end up in the sludge and pollute the environment. This is why sludge incineration has become more common in recent years. It is also possible to receive a positive energy balance out of incineration and utilise the calorific value of sludge. The main driver for sludge incineration has, however, been the fact that the amount of sludge generated at municipal waste water treatment plants is very large compared to the land area available for the disposal or treatment (e.g. composting) of the sludge.

In the EU, the new Waste Framework Directive (Directive 2008/98/EC) is transposed or being transposed to the national legislation of the member states. The new directive will encourage the material recycling of sludge and limit the disposal of organic matter to landfills. The former requirement is likely to promote the disposal of sludge to agricultural land, provided that it is otherwise accepted by the farmers and competent environmental and agricultural regulatory authorities. The latter requirement will encourage or oblige the sludge producers to incinerate sludge unless it cannot be otherwise disposed of.

Figure 8-1: Mono-combustion plant VERA in Hamburg. Photo: VERA Klärschlammverbrennung GmbH.

For instance, in Hamburg and Berlin Ruhleben, over 150 000 t sludge is burned annually. Also, many Polish cities, including the PURE partner cities Gdansk and Szczecin, as well as St. Petersburg in Russia apply sludge incineration at their waste water treatment plants.

8.2 GENERAL REQUIREMENTS AND DIFFERENT SOLUTIONS FOR SLUDGE INCINERATION

Sludge can be either co-incinerated with other sources of energy, such as municipal solid waste or fossil fuels, or mono-incinerated using other fuels only as support. The design criteria for sludge incineration in different types of boilers depend on the mixture and heat values of different fuels. Sludge incineration is applied for digested, dewatered and possibly dried sludge. Sludge may be incinerated without drying and without digestion; however, in this case additional fuel is often required.

In case of mono-combustion, the proportions of sludge and support fuel such as coal, oil or natural gas depend on the dry solids and ash contents of the sludge. Depending on the incoming dry solids content – if it is 90 % or more – sludge can be incinerated in mono-combustion with very little, if any, support fuels. However, for plant start-up and often for normal continuous operation, the support fuel and incineration system is kept ready in order to better manage the dry solids content fluctuations of the incoming sludge. In case of co-combustion, there is usually enough coal, municipal solid waste or other solid fuels available, and thus no additional support fuel is needed.

In general, the dry solid content and heat value of the sludge – as well as other fuels – should be as high as possible. The typical heat value of the dry solids of sludge is 3–5 MJ/kg DS and it depends mainly on the ash content of the material. Of course, the heat value of the sludge also depends on its water content as well as whether the sludge is digested or not. The optimal dry solids content depends on the heat values of other fuels used; if the average heat value of other fuels is very high, the dewatered sludge can be incinerated in dry solids content between 20–30 %, i.e. without any thermal drying of the sludge at all. In Bottrop near Essen in Germany, there is an example of co-combustion of municipal sludge with

Figure 8-2. Incineration in St. Petersburg. Photo: Lotta Ruokanen.

coal (Schmelz, 2011) and in the pulp and paper industry there are lot of examples of co-combustion of wastewater sludge and wood residues.

One important task in sludge incineration is to achieve as good turbulence in the furnace as possible. In order to achieve this, excess combustion air is fed to the furnace. However, as the excess air consumes heat, its amount should be optimised, and the incoming combustion air pre-heated with the flue gases prior to it entering the furnace. This system is called the heat recovery system of the boiler.

It is worth noticing that even though municipal solid waste can be incinerated in rotary kilns – a practice widely applied in the cement industry in Germany and several other countries – sludge is not a suitable fuel for this incineration technology. This is because the sludge would not behave like other solid fuels, but would form balls which would roll through the kiln and would not be completely combusted.

Operation, maintenance, environmental and safety aspects

The operation of incineration technology usually has to take place continuously on 24/7, since daily or weekly shut-downs entail excessive costs. Operation and maintenance is professionally much more demanding than other unit operations of sludge handling. Boilers are technically regulated due to the high operating temperatures and pressure vessels – both require individual authorisation of the responsible and licensed operator in charge.

Environmental issues with sludge incineration are associated with flue gas emissions and the disposal of ash (see section 9.4). Air emissions of flue gases can be controlled with flue gas cleaning equipment designed to remove particulate matter and gaseous emissions like sulphur and nitrogen oxides.

8.2.1 Co-combustion

The co-combustion of mixtures of different solid, liquid and gaseous fuels has been applied for decades and can thus be considered proven technology. The incineration of municipal or industrial waste water sludges is more common in Germany and Finland than the other countries in the Baltic Sea Region.

In Germany, the sludge is co-combusted mainly with coal or municipal solid waste; in these cases, the ash contains so little phosphorus and such a large amount of impurities that phosphorus recycling cannot be considered. In Sweden and Finland, a lot of industrial waste water sludge is incinerated with bark or other wood-based materials. If municipal waste water sludge would be co-combusted in these boilers – which is not yet taking place – the ash would contain a significant amount of phosphorus and would be suitable for phosphorus recovery.

Co-combustion with other fuels or waste materials often offers benefits of the economy of scale, since the boiler should be designed for at least 25 000 tDS/a, and the optimal size of co-combustion would be at the scale of 200 000–250 000 tDS/a with all fuels used. The overall energy efficiency of these co-combustion plants are 70–85 % due to the high average heat value of the mixture of different fuels and because both heat (for process or district heating systems) and electrical power can be generated.

The share of sludge in co-combustion is typically 5–15 %; it has to be below 20 % of the fuel mixture by weight with grate fired boilers. Investment costs of the whole co-combustion boiler range usually from EUR 60 million to EUR 100 million depending on the capacity. The additional investment costs due to sludge incineration are approximately from EUR 3 million to EUR 5 million. The co-incineration plant is usually owned and operated by an external coal boiler operator or by a waste incineration operator – not by the waste water treatment plant.

8.2.2 Mono-combustion

Mono-combustion is usually designed for the simple destruction of sludge without energy recovery because the net heat value of sludge does not produce excess energy. If the sludge is digested, the heat value is even lower. The typical heat value of the dry solids of sludge is about 3 MJ/kg DS. The mono-combustion therefore only consists of fuel reception, mixing and feeding systems, a furnace with burners of support and start-up fuels like oil, natural gas or coal, or biogas from digestion.

The investment costs of simple mono-combustion are less expensive than that of co-combustion, but the operating costs are much higher because of the need for support fuel and missing revenues from the sales of heat and electrical power.

The number and total capacity of mono-combustion plants is much smaller in the Baltic Sea Region than the number and total capacity of co-combustion plants. Mono-combustion is more appropriate for phosphorus recovery since the ash contains phosphorus and there are less impurities, such as heavy metals, than in the ash from co-combustion. The amounts of heavy metals or other inert impurities that remain in the incineration ash depend on the amount of them in the sludge.

Investment costs of the mono-combustion boiler range usually from EUR 20 million to EUR 40 million depending on the capacity. A mono-incineration plant can be owned and operated either by an external waste incineration operator or by a large waste water treatment plant itself (or an association of several medium-size waste water treatment plants).

8.3 SLUDGE INCINERATION TECHNOLOGIES

Both grate-firing and fluidised bed technologies are applied with co-combustion. Fluidised bed technology is, in practice, the only suitable technology for mono-combustion.

8.3.1 Grate-fired combustion

Operating principles

Waste water sludge is usually considered as waste. Most waste-to-energy plants use grate firing technology. There are various types of grates on the market depending on the manufacturer. Different grate types differ from the ways the fuel is conveyed into the combustion chamber. The fuel is fed into the furnace either mechanically or hydraulically.

The feeding of primary and secondary air to the boiler and into different combustion zones is somewhat different with different manufacturers. Combustion temperatures increase gradually inside the furnace and are typically 850–1 000 °C at the highest. The grate is cooled with the primary air or with water depending on the manufacturers design. More detailed information can be obtained from the manufacturers.

Unit consumptions and manpower

The installed power is 300–500 kW due to primary and secondary air blowers and flue gas equipment. The electrical power consumption of this unit process can be significant (app. 400–1 200 kWh/t DS) compared to the overall consumption of waste water treatment; further, the equipment has to be operated

Figure 8-3:Incineration in Szczecin, Poland. Photo: ZWiK Szczecin.

continuously. No chemicals are needed for sludge incineration. This unit process requires 4–5 persons more manpower and additional skills and special competences – for the thermal processes, pressure vessels, maintenance of the explosion risk zones, etc. – are needed beyond the normal operation of the waste water treatment plant.

Use in the Baltic Sea Region

Sludge and municipal solid waste co-incineration with grate firing are well-known and proven technologies in central Europe. This technology is not yet very widely applied in the Baltic Sea Region except for Germany, where co-incineration with coal has been practised in e.g. Bielefeld, Bremen Farge, Duisburg and Veltheim.

8.3.2 Fluidised bed combustion

Operating principles

Fluidised bed incineration technology can be used for 100 % sludge (mono-incineration) or with 10–50 % sludge and the rest being other usually solid fuels (co-incineration). In fluidised bed technology, combustion takes place in a furnace which consists of a boiler grate floor made of fluidising nozzles, a refractory lined furnace and a fluidised sand bed.

Fuel is fed mechanically or hydraulically to the furnace above the fluidised bed. Fluidisation is done by primary air which is blown through a nozzle grid. The sand remains as a one-meter deep bubbling layer on the bottom of the furnace. Fuel drying, volatilisation, ignition and combustion takes place in the fluidised bed.

The temperature in the free space above the bed (the freeboard) is usually between 850 and 950 °C. Above the fluidised bed material, the free board is designed to allow the retention of the gases in the combustion zone. In the bed itself, the temperature is lower – around 650 °C or higher. Staging the combustion

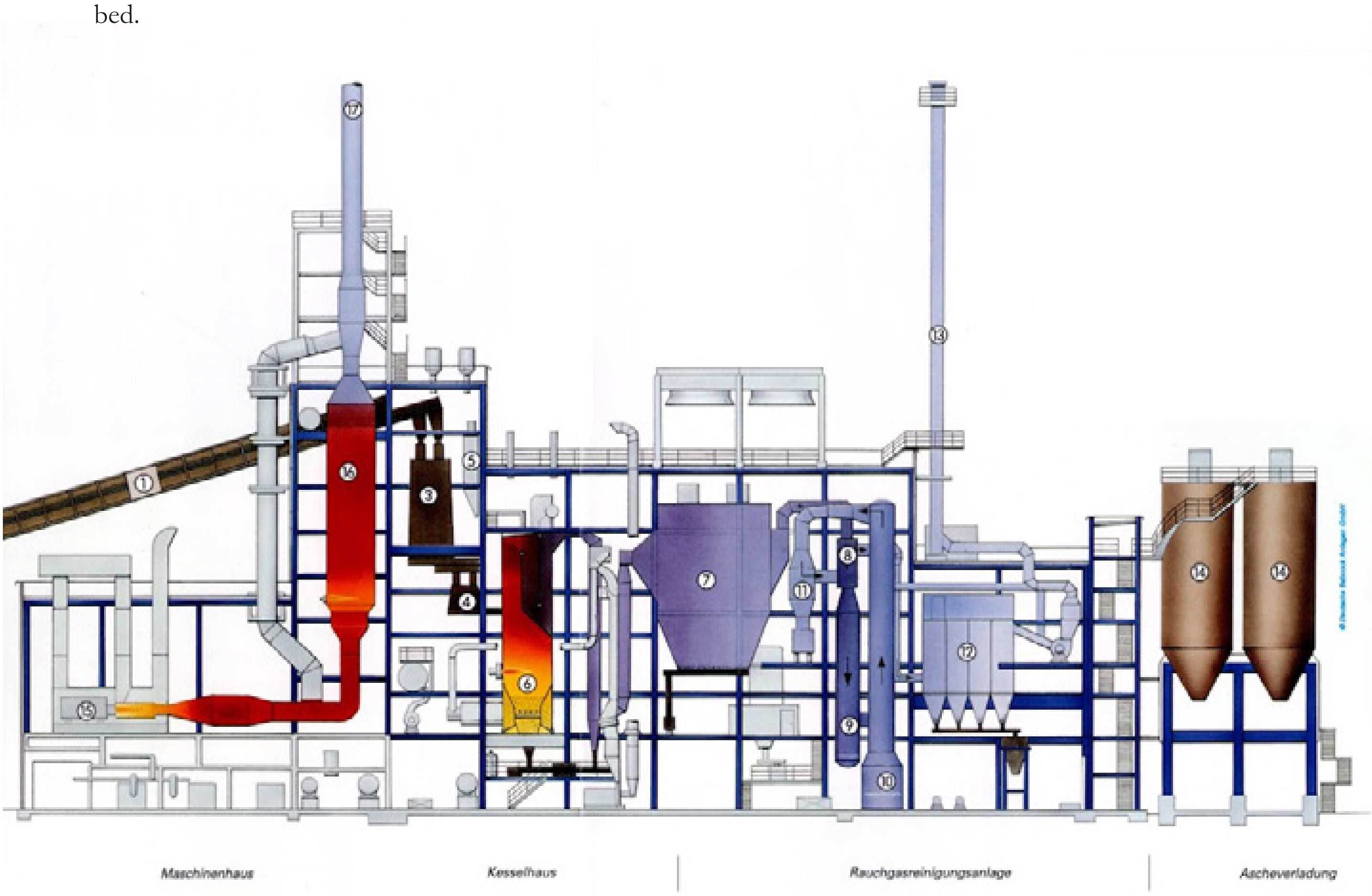


Figure 8-4: Diagram of the fluidised bed combustion in Hamburg. Picture: VERA Klärschlammverbrennung GmbH.

is carried out by secondary air which can be divided into two different injection levels. The residual char and larger fuel particles are combusted inside the sand bed.

The boiler needs a constant feed of new sand because the main combustion in fluidised bed technology takes place in a fluidised sand bed, and during combustion part of the sand is taken away through the bottom ash system and a part flies away with the flue gases. This is usually done by providing a sand silo with a feeding system. If necessary, part of the sand can also be recycled through a recycling system placed alongside the bottom ash removal system. More detailed information can be obtained from the manufacturers.

Costs, unit consumptions and manpower

The investment cost range is from EUR 20 million to EUR 40 million depending on the capacity and type of energy recovery and other factors. The technical lifetime of the equipment is usually 20–25 years.

The installed power is 400–600 kW due to primary and secondary air blowers, fluidised bed circulation and flue gas equipment. The electrical power consumption (app. 400–1200 kWh/t DS) of this unit process can be significant compared to the overall consumption of waste water treatment; further, the equipment has to be operated continuously. No chemicals are needed for sludge incineration. This unit process requires 4–5 persons more manpower and additional skills and special competences – for thermal processes, pressure vessels, maintenance of explosion risk zones, etc. – are needed beyond the normal operation of the waste water treatment plant.

Use in the Baltic Sea Region

Sludge and solid waste incineration with fluidised bed technology are well known and proven technologies in industrial plants in the Baltic Sea Region. They have been applied in a few large waste water treatment plants for the mono-combustion of sludge, for example in Copenhagen, Denmark; St. Petersburg, Russia; and in Poland (e.g. in Cracow, Gdansk, Lodz, Pomorzany and Szczecin). Outside the Baltic Sea Region, this technology has been applied in the UK, the Netherlands, Switzerland, Austria, France and Italy.

8.4 SUMMARY OF MAIN INCINERATION METHODS

Table 8-1: Grate-fired and fluidised bed combustion.

Technology	Features	Applicability	Remarks
Grate-fired combustion	Combustion in a furnace at 850–1 000 °C which consists of a grate floor and refractory lined furnace.	Not suitable for mono-incineration of sludge. Applicable for co-combustion of sludge, and the share of sludge < 20 %.	Investment costs EUR 60 million to EUR 100 million. Installed power 300–500 kW. Requires additional 4–5 persons with special competences; the plant is not normally operated by the waste water plant personnel.
Fluidised bed combustion	Combustion in a furnace at 850–950 °C which consists of a boiler floor made of fluidising nozzles, refractory lined furnace and sand bed.	Suitable for both mono-combustion and co-combustion of sludge.	Investment costs EUR 20 million to EUR 40 million. Installed power 400–600 kW. Requires additional 4–5 persons with special competences; with mono-incineration it can be operated by the waste water plant personnel.

Photo: Shutterstock.com/Hywit Dimyadi.

9.1 INTRODUCTION

In the past, sewage sludge has been disposed to landfills, stored in huge sludge ponds, dried in the sun in arid climates or dumped to the oceans. More recently, beneficial uses for dewatered sludge and ash from sludge incineration have been developed. The more advanced methods of sludge or ash disposal are usually targeting to reuse the composted or digested sludge in agriculture as a fertiliser or in landscaping, or reuse phosphorus and/ or nitrogen in agriculture as an additional fertiliser.

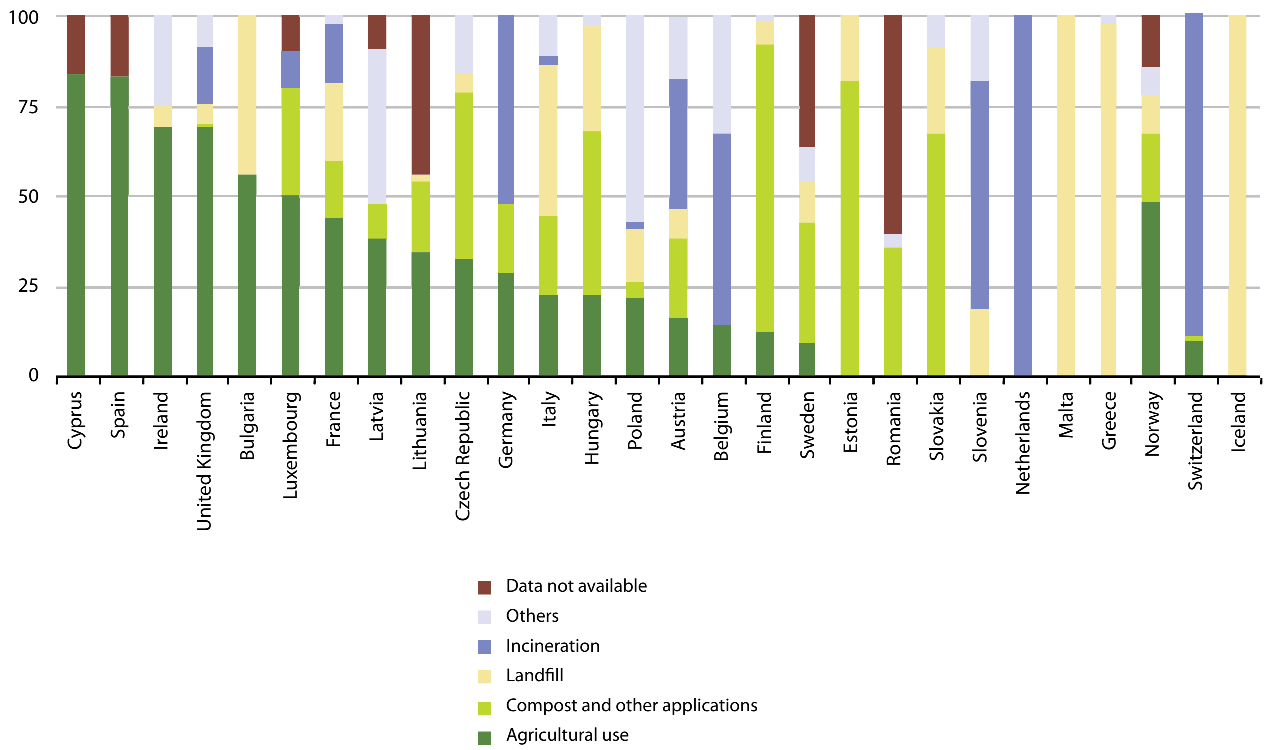
In Europe and in the Baltic Sea Region countries there are various sludge disposal strategies in use. Countries like the Netherlands, Belgium and Switzerland have forbidden or restricted the agricultural disposal of sewage sludge and is incinerated. Other countries like Finland, Estonia and Norway use composted sludge for green areas, for example. Some countries like Iceland, Malta and Greece are or have been completely disposing to landfill. In Russia and Belarus, collecting sludge to sludge pits or ponds is common.

Sewage sludge has high concentrations of nutrients like phosphorus, nitrogen and carbon as well as contaminants like heavy metals (e.g. cadmium, mercury) and organic pollutants (e.g. PCBs). The concentrations in the sewage sludge always depend on households and industry in the area from where the waste water treatment plant gathers the sewage. High concentrations of copper and zinc are often caused by households, and cadmium, chromium, mercury and lead mainly by industry. Low concentrations of harmful substances mean that sludge can theoretically be used in agriculture. National regulations and the political intent often contribute to what methods are applied in practice.

Due to the high organic matter content of the sludge (with or without digestion), it is possible to burn dried sludge in an incineration plant and reduce its volume. It is also possible to produce excess energy and to use the sludge to gain electrical or thermal energy (see chapters 7 and 8). After incineration, the question on ash disposal still has to be solved.

In many countries, disposing sludge to landfills is decreasing and in some countries it is even forbidden (see chapter 12). Disposal to landfill loses the potential of sludge as a resource of nutrients or energy.

Figure 9-1: Sewage sludge disposal from urban waste water treatment, by type of treatment, 2009* (% of total mass). Source: Eurostat.



* Belgium, Germany, Luxembourg, the Netherlands & Austria, 2008; the Czech Republic, Ireland, Latvia & Slovakia, 2007; Greece & Switzerland, 2006; Italy, Cyprus and the United Kingdom, 2005; France and Hungary, 2004; Iceland, 2003; Sweden, 2002; Finland, 2000; Denmark and Portugal, not available.

9.2 USE OF SEWAGE SLUDGE IN AGRICULTURE

The use of municipal waste water sludge in agriculture has been practised in the Baltic Sea Region for at least 40 years. The interest for agricultural disposal of sludge varies from country to country in Europe and in the Baltic Sea Region. Also, within the borders of one country like Germany, the differences can be significant: in northern Germany, the share of agricultural disposal is over 60 %, whereas in the southern part of the country it is under 20 %. Pollutants, as well as the possibility of hygienic contamination, have raised scepticism among the agricultural sector, politicians and the public towards the agricultural use of sludge. New phosphorus recovery technologies are anticipated to allow the recycling of nutrients from sludge to agricultural use in the near future.

In the 1950s and 1960s, the regulations concerning the agricultural use of sludge were less strict. Over the years, the knowledge on the potential adverse impacts of sewage sludge in agriculture has increased – there are heavy metals and organic pollutants in the sludge. The analytical methods in the laboratories have improved, new substances have been discovered and new or more stringent restrictions may be expected.

The concentrations of heavy metals in sewage sludge have decreased in the last 20 years in many countries. In the UK, for example, the reduction varies from 59 % to 85 % (Palfrey, 2011), and in Germany from 20 % to over 90 % (Bergs, 2010). Especially the parameters concerned as critical (mercury, cadmium, lead and chromium) have decreased. The range in the EU of these concentrations is high and the data do not cover the whole Baltic Sea region (Table 9-1). There are legislative limit values for heavy metals in all the countries of the Baltic Sea region (chapter 12).

The concentrations of heavy metals and nutrients depend on the waste water treatment process. A good treatment increases the contamination as well as the nutrient content in sludge. Neither industrial fertilisers are – depending from where they originate from – free from contamination. Some sources of mineral fertilisers have high concentrations of cadmium and uranium. In the legislation of some countries, higher cadmium loads are allowed if the phosphorus concentration is high enough (Germany, Bergs, 2008). In sewage sludge, high concentrations of cadmium und uranium are not usual.

Figure 9-2. Sludge use in forest cultivation in Latvia. Photo: SIA Rigas Udens.

An environmentally-sound agricultural use of sludge requires sufficient pre-treatment of the sludge. It is possible to use liquid sludge without dewatering for agriculture – in Germany this is practised – but the amount has to be controlled for groundwater protection. The use of dewatered or dried sludge is recommended. Solar drying and reed beds can be suitable for small and medium-size plants as pre-treatment for agriculture use. In northern regions, the climate is too cold for solar drying (see chapter 7).

Often, fertilisation with sewage sludge is only allowed at a certain time of the year and directly into the soil. Treatment methods like composting or chemical sta-

Table 9-1: Concentration in sewage sludge in mg/kg dry solids (DS) (Palfrey, 2011).

	Cd	Cu	Ni	Zn	Pb	Hg	Cr
EU sludge average (2006)	1.9	207	27	715	52	1.5	50
EU sludge range	0.4–6.9	73–356	11–66	332–1 235	8.9–114	0.2–4.6	14–127

bilisation with lime to eliminate all pathogenic bacteria are recommended but often not required. Sludge regulations are described in detail in chapter 12.

In addition to heavy metals and pathogens, the presence of organic compounds such as polyaromatic hydrocarbons (PAH), adsorbable organic halids (AOX) and polychlorinated biphenyls (PCBs) may restrict the use of sludge in agriculture. In the last few years, new concerns have emerged concerning organic micropollutants like hormones, residues of other drugs and fire protection compounds originating from modern clothes, etc. In Germany, the maximum amounts of polymer residues are being considered for future regulations. The issue with organic micropollutants is currently somewhat open and requires follow-up by the waste water treatment operators and regulatory authorities in the Baltic Sea Region.

The prices of industrial fertilisers for farmers in comparison with sewage sludge depend on the competitive situation in each country as well as eventual subsidies provided to industrial fertilisers like as is the case in Russia. In general, the average price level of fertilisers has increased over the last 3–5 years.

The interest in production of fertilisers from sludge is growing – at least outside the Baltic Sea Region as in Norway and the Netherlands – either by means of drying and pelletizing, or incinerating sludge and using the ash as fertiliser or as feedstock in fertiliser production (see 10.4 and 12). The agricultural disposal of sludge, as such, may decrease when new technologies of phosphorus recovery are available (see chapter 11). The recovery of phosphorus from sludge is not yet economically profitable.

9.3 DISPOSAL OF SEWAGE SLUDGE TO LANDFILL

In the European Union, a widely applied practice has been to dispose of the sludge that cannot be used in agriculture or landscaping to landfills. Landfills also require landscaping when a certain landfill area has reached its final height and sludge has been suitable material for this purpose.

The only quality requirement for landscaping landfills with sludge is that it cannot be in liquid form, corresponding to the general restrictions to dispose of any liquid materials to landfills. The recent limitations or bans on the of disposal of biodegradable material to landfills will also limit the disposal of sludge to landfills and the use of composted sludge as a landscaping material in the long run. This limitation does not exist in the non-EU-countries. These restrictions will lead to an increase in the need and pressure to find beneficial uses for sludge in agriculture, landscaping of parks, roads and railways, for example, and also for the incineration and treatment of the ashes.

Figure 9-3. Ash from sludge incineration in St. Petersburg, Russia, and a product made of it. Photo: Lotta Ruokanen, HELCOM.

9.4 DISPOSAL OF SEWAGE SLUDGE ASHES FROM MONO-INCINERATION

Sewage sludge ash is the product of sludge incineration (see chapter 8). Only ashes from the mono-incineration of sludge and mixtures with other ashes with high concentrations of phosphorus and other nutrients can be used for further treatment and recycling. Ashes from co-incineration have a very low concentration of phosphorus and possibly too high contaminant levels if co-incineration takes place, for example, with municipal household waste – and are usually disposed to landfill. Sludge burned in a cement factory does not have a disposal problem because the ashes are bound in the product.

After incineration, the concentrations of nutrients are approximately doubled, depending on the organic matter content of the sludge before incineration. The estimated phosphorus content of mono-incinerated sludge varies between 8 and 20 %. Organic micropollutants are destroyed in incineration and mercury is removed in the exhaust gas cleaning. Unfortunately, the concentrations of all other heavy metals increase in incineration, which may prevent direct fertilising.

After incineration, the phosphorus is chemically bound in the ash and the bioavailability is low. The possibilities for treatment and the use of sewage sludge ash in agriculture are described in chapter 11. Before a possible future treatment that makes the phosphorus biologically available, the sewage sludge ash should be stored and disposed for a later treatment in a 'mono-landfill'. The use of ash is an actual field of research and one of the main challenges of the beneficial use of sludge in the coming years.

In 2012 in the Baltic Sea Region, many regulations are in place to restrict the use of ashes in agriculture (see chapter 12). Sludge is classified as waste, and as ash from waste incineration is primarily classified as hazardous waste, the beneficial reuse or material recycling of sludge incineration ash requires special permission. In most countries in the Baltic Sea Region, this is the prevailing interpretation – a major obstacle for expanding the use of mono-incineration ash in agriculture. In Germany (and outside the Baltic Sea Region in the Netherlands), however, there have recently been initial attempts to solve this problem and enhance the material recycling of phosphorus from mono-combustion. The disposal of ash to landfills (or dedicated special storage areas for the future reuse of it) from mono-incineration can also be restricted and/or special requirements can be set, as the sludge from incineration is considered comparable to ash from waste incineration.

9.5 SUMMARY OF THE DISPOSAL METHODS

- Several methods to dispose of sludge exist; the sludge disposal strategies followed by each country in the Baltic Sea region are not uniform.
- The agricultural use of sludge or incineration and the disposal of ashes allow the utilisation of sludge as a material or energy resource; these are quite common methods in the region.
- Composted or otherwise hygienised sludge is used in some countries in the region for green areas such as parks.
- The availability of nutrients in the sludge depends on the waste water treatment process in use.
- Contaminants present in the sludge restrict its use for agricultural purposes: although concentrations of heavy metals have been reduced in many countries, some new concerns have emerged.
- Ash from only mono-incinerated sludge is phos phorus-rich and contaminant-free enough to be used in agriculture.
- The availability of nutrients is low in ashes and requires additional treatment methods which are still under development work.
- Sludge pits and ponds are still used in some parts of the region; this is not a sustainable way of managing sludge, as its use as a material, together with the nutrients and energy potential are lost; also, leaking sludge storage areas pose a potential threat to the water environment.
- Using sludge for landfilling will be reduced in the coming years in the EU due to new regulations and an increasing interest to recycle the nutrients from sludge.

10. REJECT WATER TREATMENT

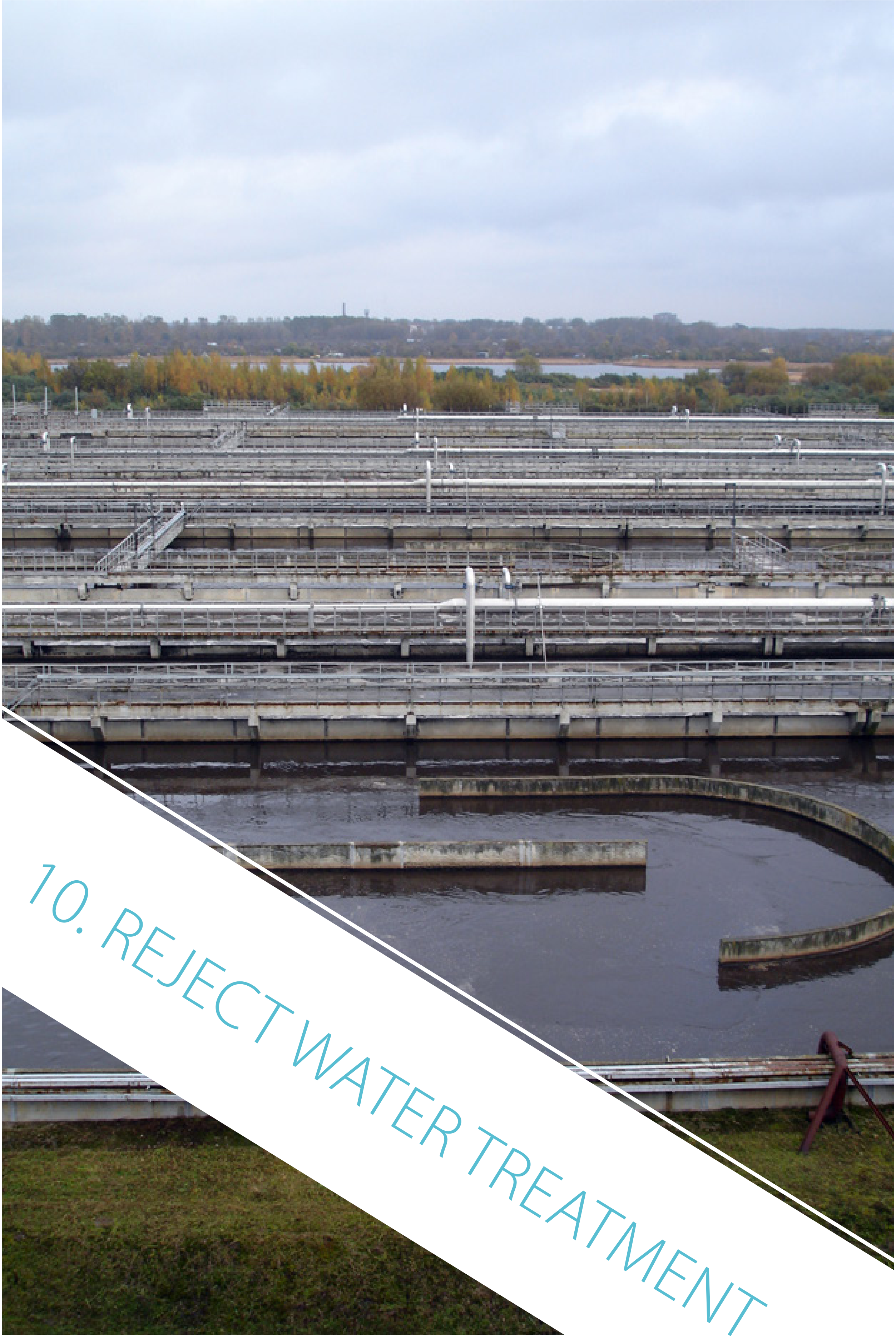


Photo: Lotta Ruokanen, HELCOM.

10.1 INTRODUCTION

Internal reject waters from anaerobic digestion, overflow from the anaerobic digester, sludge dewatering or condensates from the thermal drying contain significant loads of nitrogen, phosphorus and suspended solids. Therefore, several treatment methods for reject water have been studied and introduced in many waste water treatment plants. Also, filtered liquor from the post-processing (composting) and storage fields of digested sludge is classified as reject water. External reject waters come, for instance, from regional treatment plants for waste or sludge.

Reject water after digestion is often very concentrated: the microbiological process produces high concentrations of ammonium. Also, the phosphorus is dissolved, especially when biological phosphorus removal is taking place. Typical features for the reject water quality are high ammonium nitrogen and suspended solids concentrations with high alkalinity. The chemical oxygen demand (COD) concentration is high; however, the reject water does not contain much of easily degradable organic material (BOD). Phosphorus is adsorbed to the suspended solids fraction. In addition, the settling properties of suspended solids are poor.

Most of the reject water treatment methods target to reduce its nitrogen content as the waste water treatment process is sensitive to high loads of nitrogen, especially if not fed continuously. Continuous feed depends on the dewatering method and operation shifts. If the reject water is discharged 24/7 and there are operation problems or nitrogen removal is insufficient, a separate reject water treatment is recommended. If a chamber filter press is used, or operation is not running 24/7, a buffer tank can often solve any problems.

Good to know:
If lime is used as a flocculation aid, separate reject water treatment is not recommended due to calcium carbonate accumulation.

The reject water load can be reduced either with chemical and mechanical or biological treatment methods. The amount of reject water can be estimated if the quality and amount of the used feed sludge is measured and the digestion process is stable. Essential for the reject water quality is how well the sludge dewatering works and what kind of sludges are used.

10.2 REJECT WATER PHYSICAL/CHEMICAL TREATMENT PROCESS

There are different possibilities for the physical or chemical treatment of reject water. Most treatment processes are designed for nitrogen removal, e.g. the use of zeolite or ammonia stripping.

Operating principles and performance results

The most common chemical treatment process for nitrogen removal is ammonia stripping. Ammonia can be removed from water by the balance reaction between ammonia nitrogen (NH_4^+-N) and ammonia (NH_3). The following balance reaction is utilised in ammonia stripping:

NH_4^+ (aq) + OH-(aq) > H_2O + NH_3 (gas),

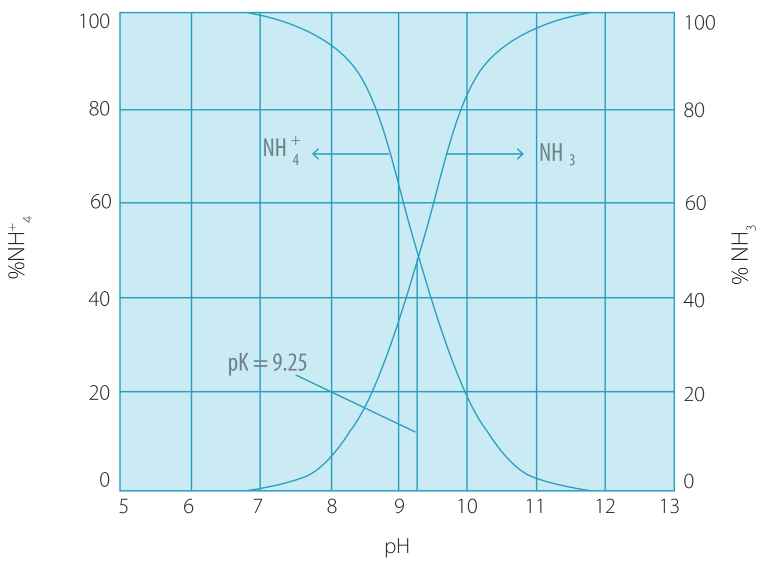


Figure 10-1: Equilibrium diagram for ammonia (NH_3) nitrogen and ammonium (NH_4^+) with changing pH value.

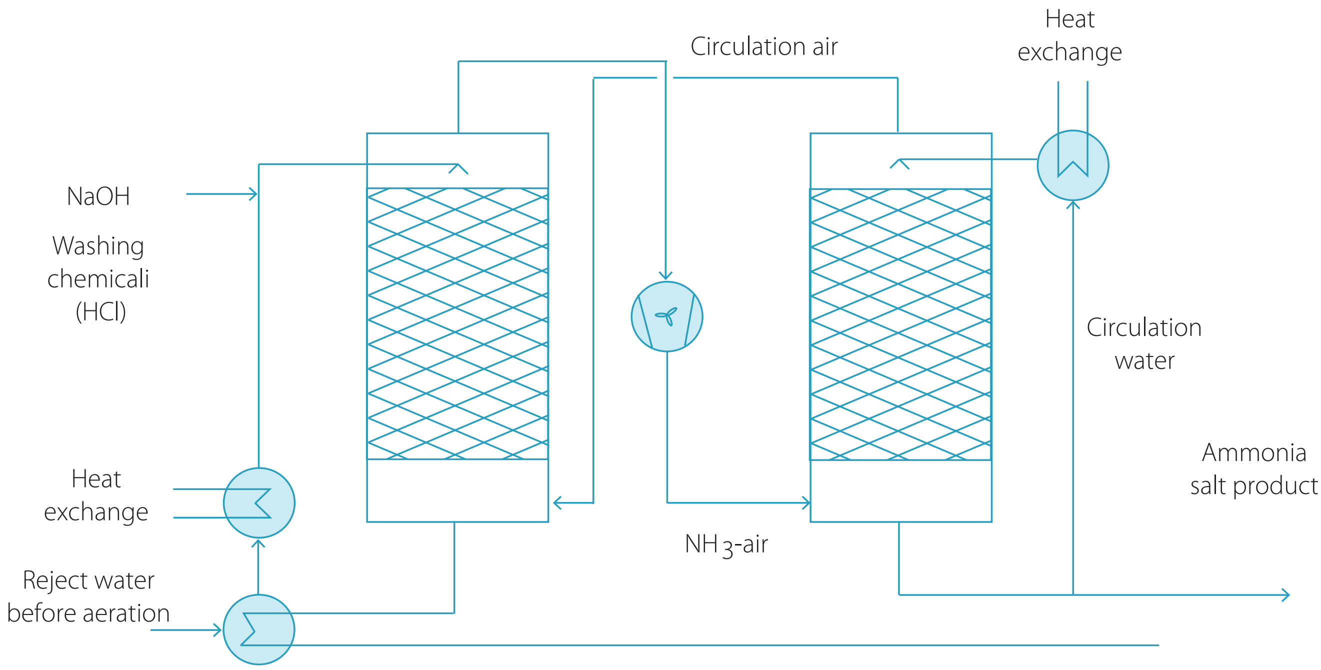


Figure 10-2: Principal process scheme of ammonia stripping process.

where (aq) means aqueous solution. The stripping takes place by increasing the pH value. The higher the pH, the more NH_4-N is in ammonia form. At high pH (> 10) most of the ammonia nitrogen is in NH_3 form (Figure 10-1).

In ammonia stripping, the pH of the reject water is raised and the temperature is raised for some time as this also favours the transition towards the ammonia side of the balance. After this, the reject water is lead through an aeration tower where the gaseous ammonia is transferred to the air phase. The air then flows to a scrubber where the ammonia is transferred to liquid form; if an acid is used, an ammonia salt is formed (Fig. 10-2). The idea is to sell the ammonia salt or the concentrated liquid as a fertiliser.

Operation, maintenance, environmental and safety aspects

The operation of this technology usually takes place continuously 24/7. If the dewatering is working intermittently, a buffer reactor is needed to balance the fluctuations in flow.

The operation of the reject water treatment process requires more chemical skills than the operation of the sludge handling equipment. Ammonia release can be an environmental and occupational health and safety problem. Clogging in the towers can be a safety problem because they have to be cleaned manually.

Costs, unit consumptions and manpower

Investment costs of the stripping process treatment range from EUR 2 million to EUR 4 million depending on the capacity. The technical lifetime of the equipment is usually 15–20 years.

The cost of chemicals is very high and depends on the buffer capacity of the water, the concentrations of substances in the reject water and on the intended end product.

Figure 10-3. Photo: Shutterstock.com/Hansenn.

Use in the Baltic Sea Region

There are some references of stripping process in Finland at Biovakka Oy's sludge and biowaste biogas productions sites in Topinoja, Turku and Vehmaa. The Topinoja plant only treats municipal sludge from Turku's waste water treatment plant, while the Vehmaa plant treats municipal sludges with animal manure from large-scale agriculture. Ammonia stripping is a process that is mainly used in industry at processes with very high nitrogen loads. It is not very often used at waste water treatment.

10.3 REJECT WATER BIOLOGICAL TREATMENT PROCESSES

The biological technologies for reject water treatment are the same as for nitrogen removal in general. The most common is the traditional denitrification-nitrification process (DN process), which is boosted with an external carbon source for better denitrification. The carbon source is needed to reach a favourable ratio of nitrogen and carbon. In practice, this method has not been functioning satisfactorily and therefore alternative methods have been developed. The methods are not yet widely proven.

10.3.1 Denitration / nitration process

A development of the denitrification and nitrification process is the nitritation and denitritation process. Ammonia is oxidised to nitrite and then reduced to molecular nitrogen. The total energy consumption is lower (up to 40 % savings) and only 60 % of carbon source is needed compared to the traditional nitrogen removal process. This application is possible because the forming of nitrite is separated from the nitrification. Factors like the concentration of ammonia, temperature, oxygen and pH value are important (Beier et al., 2008). There are different commercial applications, e.g. SHARON®, SAT or PANDA.

10.3.2 Deammonification

The deammonification process was developed in the 1990s. Many plants utilising this process are in operation in the Netherlands. The process is based on the activity of bacteria *Planctomycetes*, capable of using nitrite and ammonia at anoxic conditions. The reaction product is molecular nitrogen (N_2) and no carbon source is needed.

This procedure can be implemented in two ways:

- Two-step deammonification utilising two different tanks are used. This process was developed from the denitritation process. Nitrite is built in the first tank; in the second tank, the nitrite and ammonia are used by the bacteria where molecular nitrogen is produced. The first tank is aerated and the second one only mixed (anoxic). The problem with this application is the high nitrite concentration in the first tank which cannot be regulated, thus the process is not very stable.
- One-step deammonification. Building nitrite and deammonification is carried out in one tank. The system is controlled with different oxygen concentrations or pH values. Commercial examples are the DEMON® and the CANON® processes.

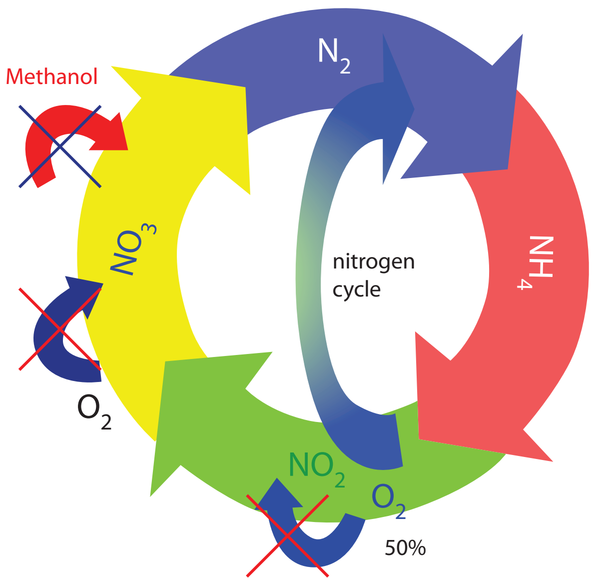


Figure 10-4: Nitrogen cycle in the nitritation-deammonification process.

The nitritation-deammonification process is an activated sludge treatment process, with an optimal operation range of 30–40 °C and a minimum temperature of 25 °C. The removal of suspended solids and COD are needed as a pre-treatment stage with the balancing of the influent flow. The process utilises two types of sludge: granular sludge generated in the process with sludge age of 100–200 days and biological sludge with sludge age of 2–10 days. The granular sludge is brought to the process as seed sludge and it starts growing because the process conditions are made favourable for such a sludge type. The process control system is based on pH value measuring.

The advantages of the nitritation-deammonification process are 60 % energy saving and low operational costs compared to the DN process; no external car-

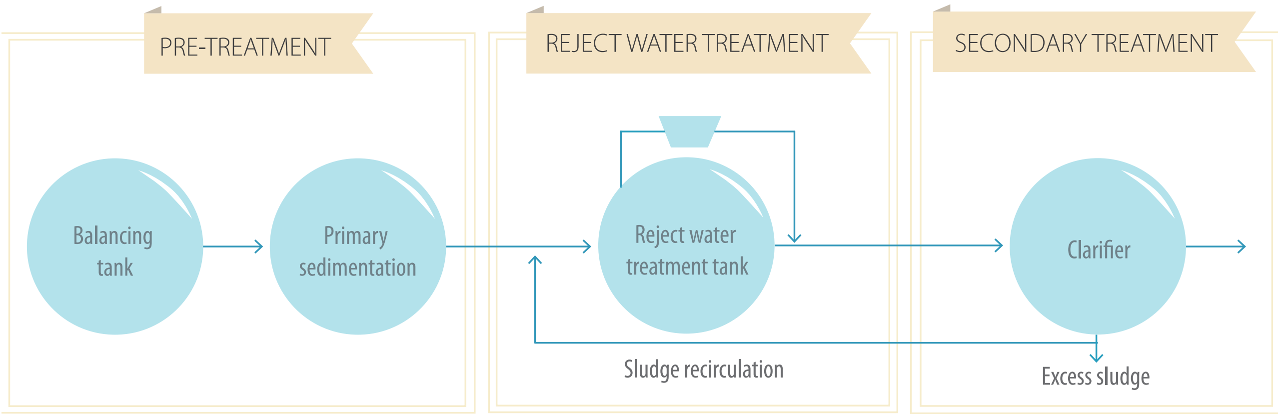


Figure 10- 5: Reject water treatment with the nitration-deammonification process.

bon source is required; no chemicals are needed to control alkalinity; and it has a very low sludge production.

The most challenging point of all these processes is the process control, which has to be stable, for example:

- the temperature requirement when the operating temperatures are under 30 °C; and
- the suspended solids requirement when the solids content is high.

Another biological reject water treatment method is the enhanced nitrification-denitrifying process in a sequential batch reactor (SBR), the commercial application being the BABE® process.

Operation, maintenance, environmental and safety aspects

The operation of biological reject water treatment technologies usually takes place continuously, just like the anaerobic digestion process where the reject waters mainly come from. If the dewatering is working intermittently, a buffer reactor is needed to even out the fluctuations. The operation of reject water treatment process requires somewhat more biotechnical skills than the operation of sludge handling equipment. There are no major environmental concerns or safety problems.

Costs, unit consumptions and manpower

Investment costs of the biological reject water treatment range usually usually from EUR 1 million to 2 million depending on the capacity. The technical lifetime of the equipment is usually 15–20 years.

The installed power is approximately 20–40 kW and the electrical power consumption of this unit process is marginal compared to the overall consumption of waste water treatment. This unit process does not need any additional manpower or special competences beyond the normal operation of the waste water treatment plant.

Use in the Baltic Sea Region

In the Baltic Sea region, the nitrogen reduction requirements in waste water treatment plants have become stricter. The internal reject water load can be even 20 % of the whole ammonium nitrogen load. The capacity of the activated sludge treatment process is often not sufficient for such a high load and therefore the reject waters are preferably treated separately.

There has been full-scale operation experience of the biological process worldwide since 2005. One example is at Lakeuden Etappi, in Seinäjoki, Finland, which is handling waste water sludge and municipal biowaste from households. There is a new plant starting up in Kokkola, Finland, using only waste water sludge as the feedstock. The municipal waste water treatment plant Himmerfjärdsverket in Sweden has a carrier-based nitritation-deammonification process and the waste water treatment plants in Linköping (since 2009) and Helsinki have tested SHARON. The waste water treatment plant in Helsinki took the nitritation-deammonification process in use for a part of their reject water during spring 2012. In the Netherlands, the SHARON process is in operation in Rotterdam, Utrecht and Zwolle, for example..

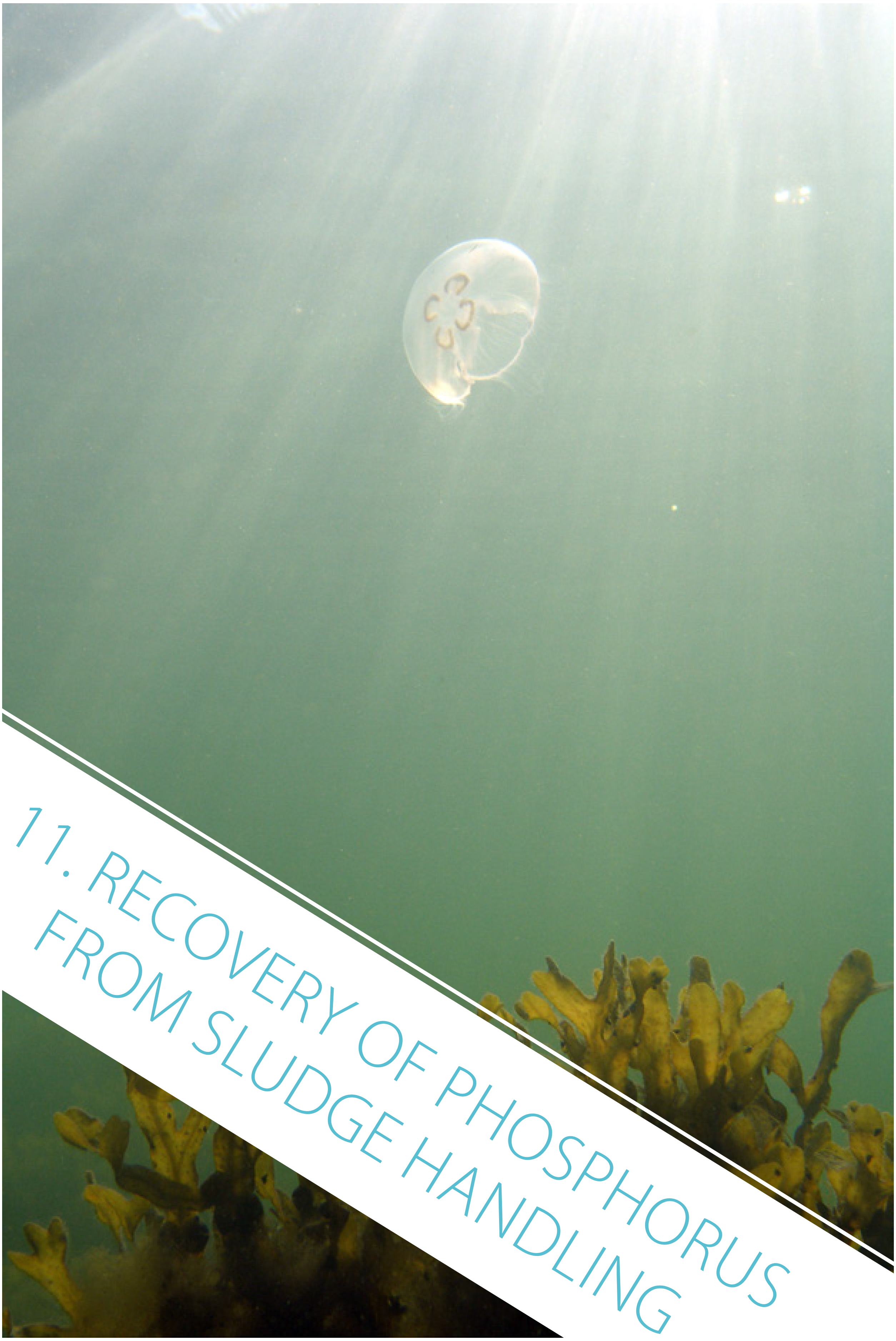
10.4 SUMMARY OF MAIN REJECT WATER TREATMENT METHODS

Table 10-1: Comparison of different methods. DN process = denitrification-nitrification process.

Technology	Features	Applicability	Remarks
DN process	A traditional DN process. External carbon source needed to achieve good nitrogen removal.	Earlier used for reject waters from the digestion of primary and excess sludges. Not used anymore because new processes are more efficient and reliable.	Investment costs from EUR 1.5 million to EUR 3 million. High operational cost because of an external carbon source (e.g. methanol).
Nitritation-denitritation process	A process without nitrification. Less energy consumption and less carbon source needed.	Sometimes used for reject water treatment as pre-stage to the deammonification process.	Investment costs from EUR 1.5 million to EUR 3 million. Operational costs are much lower compared with a DN process.
Nitritation-deammonification process	An activated sludge treatment process, producing molecular nitrogen from nitrite and ammonia. Optimal operation at 30–40 °C and minimum temperature of 25 °C.	Used for reject waters for the digestion of primary and excess sludge and applicable in medium-size and large waste water treatment plants.	Investment costs EUR 1 million to EUR 2 million. Low operational cost makes this process attractive. Installed power 20–40 kW.
Ammonia stripping	A chemical process producing a nitrogen rich fertiliser (ammonia salt).	Used for reject waters for the digestion of primary and excess sludge and applicable in medium-size and large waste water treatment plants.	Investment cost EUR 2 million to EUR 4 million. Operational cost is very high and may be a reason not to choose the alternative.

Especially with the deammonification process, there is a possibility to reduce the energy consumption, the use of carbon source and the amount of sludge. This results in lower carbon dioxide emissions.

11. RECOVERY OF PHOSPHORUS FROM SLUDGE HANDLING



Moon jelly in the Baltic Sea. Photo: Metsähallitus.

11.1 INTRODUCTION

Phosphorus is an essential plant nutrient that is used for the fertilization of field crops and also in consumer products such as detergents. Phosphorus is often the limiting factor for plant growth, and discharges of phosphorus in rivers, lakes and seas cause and excessive growth of plants and algae, i.e. a process called eutrophication with many negative consequences in the water ecosystems. Phosphorus, on the other hand, is a limited resource, which is mined only in some parts of the world, e.g. in Western Sahara (Morocco), China and the United States. Worldwide consumption of phosphorus (as P_2O_5 contained in fertilisers) has been projected to grow at a rate of 2.5 % per year over the next 5 years, with the fastest increases in Asia and South Africa (USGS, 2012).

Several studies are discussing a 'phosphorus peak', meaning that the maximum of production is already reached or will be reached soon. Some studies have shown that there are new phosphorus sources still available but mining them is not economically feasible yet. The price of phosphate rock (apatite) has been predicted to rise (see Figure 11-1), which will also increase the price of food.

Avoiding the use of phosphorus is the best possibility of saving this resource, for example in detergents like it is done in some countries (PHöchstMengV in Germany 1980, or the amendment of EU Directive EC 648/2004 on detergents). With the help of phosphorus recovery, it is possible to partly replace the production from apatite and the import of phosphorus. Recoverable phosphorus sources are:

- waste water, sewage sludge and ash from mono-incineration;
- ground animal bones and similar products;
- animal manure; and
- food waste.

Different research initiatives have been launched during recent years, for example in Scandinavia and in Germany, to recover phosphorus from sewage sludge. Individual countries have taken phosphorus recycling as an objective to their long-term strategic plans or new technology programs. Sweden has announced a long-term objective to recycle 60 % of phosphorus from sewage by 2015 (SEPA, 2002). Germany announced in 2003 the aim to develop new recovery technologies (CEEP, 2003). The Government of Finland made in 2010 a commitment to become a forerunner in nutrient recycling (MMM, 2011).

The aims of phosphorus recovery at a waste water treatment plant are:

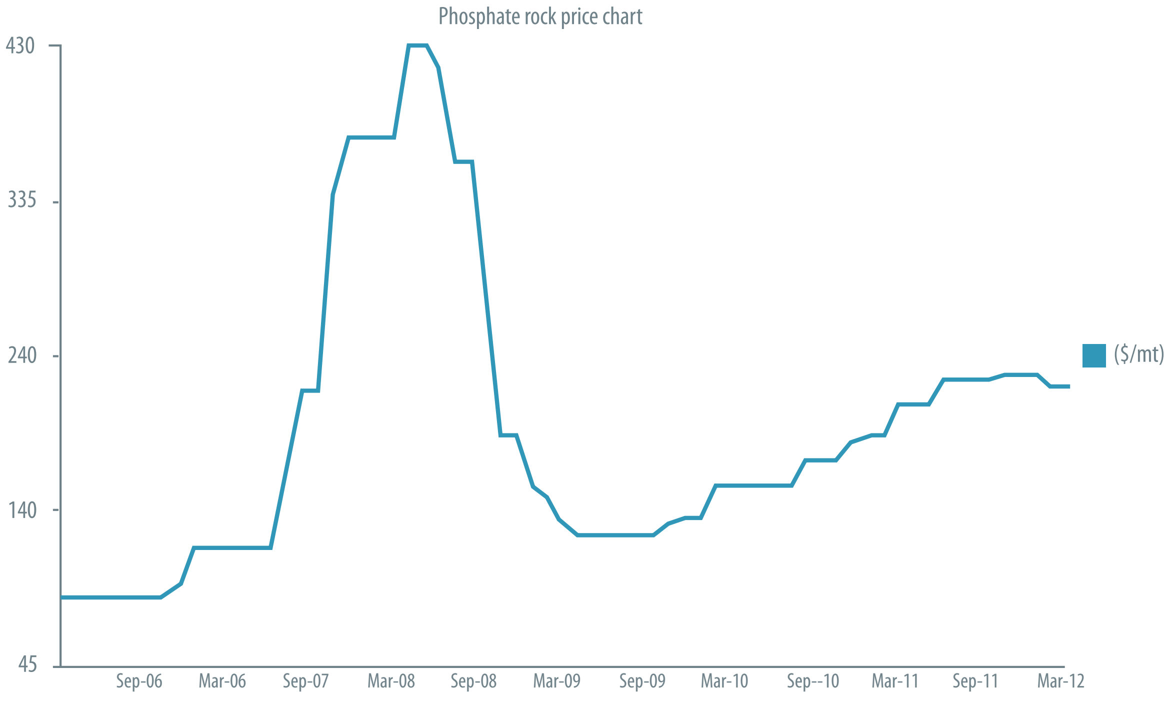


Figure 11-1: Development of the phosphate rock price in recent years. Source: www.mongabay.com.

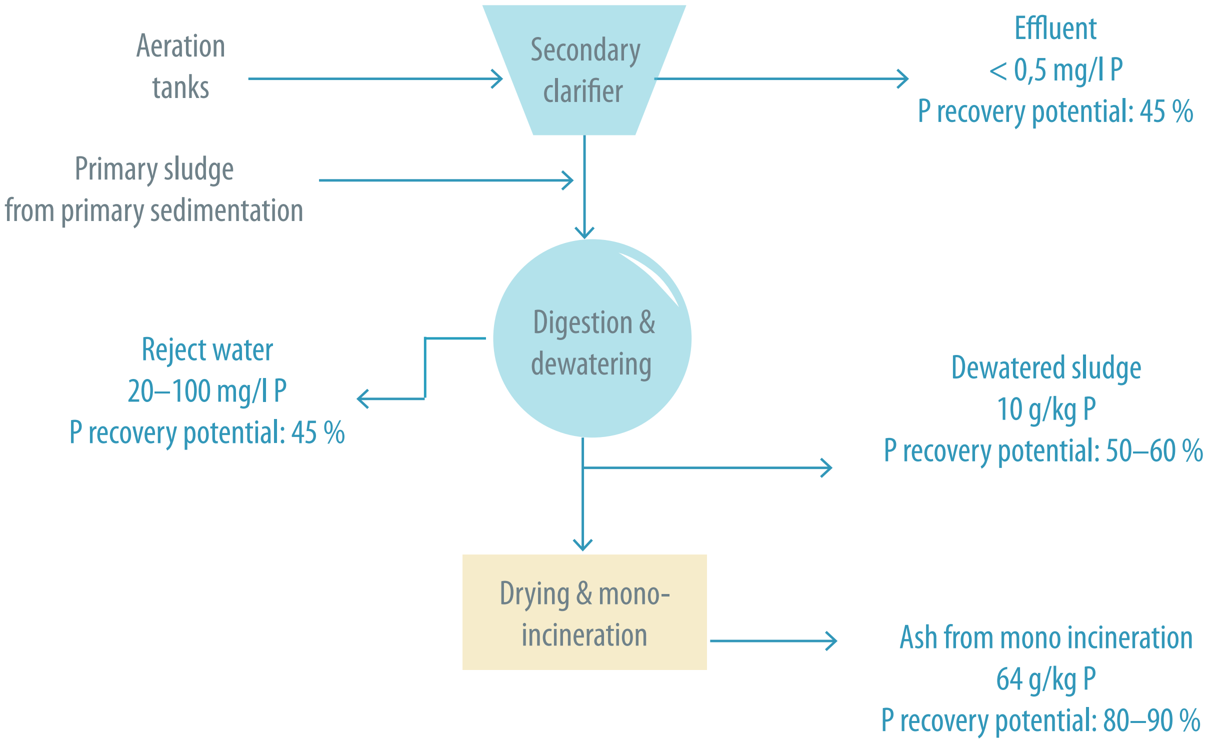


Figure 11-2: Different possibilities of phosphorus (P) recovery, typical concentrations of phosphorus and the recovery potential. Numbers: Jardin, 2010, Adam, 2009.

- recovery of a maximum amount of phosphorus with high bioavailability;
- low heavy metal concentrations;
- low concentrations of harmful organic substances; and
- economic operation of the recovery process.

The amounts of nitrogen, carbon and micronutrients are less important. At a waste water treatment plant, there are only few possibilities for phosphorus recovery (see Figure 11-2).

The nutrient recycling methods are still emerging technologies primarily developed in Europe and in North America, but the number of pilot and demonstration plants is growing rapidly. These technologies cannot yet be considered to be fully proven since the several demonstration applications have faced serious start-up problems – some have even been shut down. The technologies which are presented below cannot be recommended for a wider use. Overall, they are all expensive and not yet economical. Some technologies were developed due to operation problems and thus they are only functional in very special circumstances. For each waste water treatment plant, the basic conditions are different and depend on the waste water treatment process and the sludge treatment.

Figure 11-3: Fertiliser. Photo: Shutterstock.com/Kymmcleod.

There are two different technologies of phosphorus recycling: phosphorus recovery from ash of mono-incinerated sludge, or recovery with chemicals from waste water or sludge. At present and with the recovery concepts proposed to date, the maximum theoretical phosphorus recovery rate is about 45 % (Jardin, 2010) and 50–60% (Adam, 2009) from waste water and sludge respectively, whereas it can be up to 80 % (Jardin, 2010) or 90 % (Adam, 2009) with recovery from ashes.

Innovative methods:
The phosphorus removal process used at the waste water treatment plant affects the bioavailability of phosphorus for fertiliser use. With biological phosphorus removal, the recovery rate is high, also if the sludge is directly used in agriculture. Biological phosphorus removal may, however, cause some challenges in the waste water and sludge treatment process: worse dewatering results, sludge bulking, and the formation of struvite which blocks the pipes. Chemical precipitation with iron or aluminium causes a lower bioavailability of phosphorus. However, many waste water treatment plants applying chemical precipitation, for example in Germany, dispose their sludge to agriculture. New phosphorus recovery techniques from ashes (see section 11.3) may improve the availability of chemically precipitated phosphorus in the future.

11.2 RECOVERY OF PHOSPHORUS FROM WASTE WATER OR SEWAGE SLUDGE

The potential of recovery from waste water and sewage sludge is much lower than from the ashes of mono-incinerated sludge. Phosphorus can be recovered from the excess sludge, reject water, dewatered sludge and also from the effluent (see Figure 11-2). The effluent of the waste water treatment plant is not recommended due to too high volume and too low concentrations of phosphorus.

Additional processes to conventional waste water treatment have been recently summarised by Adam (2009), and can be based on:

- **Precipitation** such as PRISA process or AirPrex process, and
- **Crystallisation** such as Ostara PEARL, Unitika PHOSNIX, CSH process Darmstadt or DHV Crystalactor.

There are plants from pilot-scale to demonstration scale with Ostara PEARL, Unitika PHOSNIX, AirPrex and DHV Crystalactor with capacities ranging from 20 to 250 m^3/h. Although the results are more or less encouraging, more development work needs to be carried out to increase the cost-efficiency and the end-use of the recovered phosphorus.

With many of the above-mentioned methods, scaling of precipitated chemicals in pipes, pumps and the surfaces of the tanks has been a problem, one problem, that needs to be solved before the technology can be considered proven (Adam, 2009). Several demonstration scale plants have been built in Japan, Canada, USA, Germany and the Netherlands, usually with a side-stream operation. The Geestmerambacht DHV Crystalactor® plant (using $Ca(OH)_2$ and NaOH) in the Netherlands was tested in operation in the 1990s, but has since been shut down due to high operation costs.

In Berlin, Germany, the biological phosphorus removal has caused MAP (magnesium-ammonium-phosphate or struvite) precipitation in pipes since 1998. Different counteractions did not solve the problem and the costs for cleaning and maintenance were very high. After the first attempt in 2002–2009, a full-scale AirPrex process was built in 2010. Many problems were solved with the struvite being sold to be used as a raw material in fertiliser production (Lengemann, 2011).

Operating principles and performance results

Air and magnesium ($MgCl_2$) are added to the process to enable the formation of struvite (MAP). The reactor is built for a capacity of 100 m^3/h and 2–3 tonnes of MAP is gained per day (Lengemann, 2011).

The first demonstration scale reactor of Ostara PEARL (using Mg $(OH)_2$ and NaOH) with 20 m^3/h opened in Edmonton, Canada, in May 2007; other reactors are located in the USA in Portland (Oregon) and Suffolk (Virginia), started in 2009 and 2010 respectively, and the fourth reactor started operating in York (Pennsylvania) in 2010 (Ostara, 2010). The struvite production rate is designed typically to be 500 kg/d and the final product is marketed under the name Crystal Green® and used as slow release fertiliser at golf courses and municipal lawns. The reactors are fluidised bed reactors recovering nutrients from sludge liquor as struvite. The investment cost of this installation has been indicated by the technology supplier to be from EUR 2 million to EUR 3 million.

In Japan, three reactors of Unitika PHOSNIX (using $Mg(OH)_2$ and NaOH) have been built with capacities of 6–20 m^3/h. The process is a side stream process that can treat water from a number of processes including digester and biological nutrient removal systems. The sludge is pumped to the bottom of the reactor and the chemicals, sodium hydroxide and $Mg(OH)_2$, are added for precipitation and pH adjustment to 8.5–8.8. Crystals grow and sink to the bottom of the column where they are removed periodically. Fine struvite particles separated from the product struvite are fed back to the reactor as seed material. Struvite granules of 0.5–1.0 mm form in ten days retention time. The product is dewatered for 24 hours in a filter bag system or by natural drying in an ambient temperature. The processes have been reported to work satisfactorily and the struvite is sold to be used as raw material in fertiliser production (Nawa, 2009).

There are several **wet chemical processes** applied to sludge in different DS contents and with using acid, pressure, heat and oxidizing agents. The most common are the following processes (Adam, 2009): KREPRO, LOPROX, Aqua Reci and Seaborne (or Gifhorn). The results are encouraging but additional technical development work is still needed. The chemical composition of the recovered phosphorus is well known, but more technical development is needed to develop the products containing the recovered phosphorus. The Seaborne/Gifhorn process (using MgO, NaOH, Na_2S, H_2SO_4 and flocculant aid) was built to full-scale and started up in March 2010 but its operation has been stopped due to technical difficulties. The investment cost of this plant was about EUR 7.5 million (Bayerle, 2009).

The Mephrec process is a **thermal method** to recover phosphorus (Adam, 2009, Scheidig, 2009 and Petzet and Cornel, 2011). Mephrec is able to use dewatered sludge as well as also ashes out of mono-incineration. The process utilises smelting-gasification technology using metallurgical coke in temperatures of about 2 000 °C, and produces slag containing most of the phosphorus. The process can be summarised as follows: dewatered sludge is mixed with cement and burnt in a shaft furnace. Metallurgical coke, limestone or dolomite is used in the process to create the formation of slag.

Figure 11-4: Phosphorus recovery is important for soil improvement products and recycling of nutrients.
Photo: Shutterstock.com/Singkham.

11.3 PHOSPHORUS RECOVERY FROM ASHES

In the ashes from mono-incinerated sludge (see chapters 8 and 9), phosphorus is available in a high concentration, but it is chemically bound. Organic matter is burned and all harmful organic substances are destroyed. Mercury is cleaned in the flue gas treatment after incineration. All the other heavy metals, however, are present in higher concentrations than in dewatered or dried sludge. Disposing the ashes to landfill means a loss of resources and therefore cannot be recommended. Ashes from co-incineration often have too low phosphorus concentrations for phosphorus recovery caused by mixing with waste or coal.

Operating principles

There are different possibilities to reuse the phosphorus from mono-incinerated sludge:

- use of the ash after a treatment to increase the bioavailability (e.g. RecoPhos); or
- separation of heavy metals and treatment to increase the bioavailability (with acids and base by PASH and BioCon; thermal chemical by AshDec and Mephrec (Petzet and Cornel, 2010).

According to the information obtained from different technology suppliers, it seems that if the phosphorus in the ash is not converted to a more soluble form than it is after mono-combustion, the phosphorus will only be available for plants after 3–5 years (Hermann, 2012). However, there is one mono-incineration plant in the southern Netherlands which is supplying the ash to the phosphorus production of Thermphos International B.V. With the Ash-Dec process, it is possible to convert phosphorus to a more soluble form in the ash and make it available to the plants faster than without thermal treatment (Hermann, 2012). The process is basically the mono-combustion of sludge at about 1 000 °C with some added magnesium and potassium chlorides, followed by a **chemical treatment** of ash. This process is at the point of transfer to the industrial scale and the technology supplier (Outotec) is currently working on the conceptual design of two industrial projects.

Innovative methods:

While the technologies are still under development, the ashes from mono-incineration could be stored in a mono-landfill to reuse it when the technology is ready. The planning of mono-incineration plants should include storage until the recovery technology is state of the art.

Several processes are in the development and testing stage, such as SEPHOS, PASCH and BioCon, that are based on wet chemical destruction and Thermophos, which is based on thermal destruction (for more details, c.f. Adam, 2009).

Thermal treatment can be implemented either at the waste water treatment plant or at a power plant (Scheidig et al., 2009). In the latter case, the flue gas treatment can be integrated in the flue gas treatment of the power plant, which is usually more economical than a stand-alone flue gas treatment.

11.4 SUMMARY OF MAIN PHOSPHORUS RECOVERY METHODS

In 2012, many different methods and technologies are partly being employed – sometimes on a full-scale basis. Nearly all techniques have some problems, including high costs and less efficiency than planned. Many studies are being carried out in several countries, and thus a feasible technical solution is expected in the near future. Marketing these products could begin in some years, although this development also depends on the global price of the phosphate rock.

Figure 11-5: Phosphorus released to waterways causes eutrophication, for example overgrowth of filamentous algae. Photo: Samuli Korpinen, HELCOM.

12. RELEVANT LEGISLATION IN THE EU AND NATIONAL LEGISLATION IN THE BALTIC SEA REGION

Cold winters have an effect to sludge handling regulation in the Baltic Sea region.
Photo: Samuli Korpinen, HELCOM.

In this section, the relevant legislation of the European Union concerning sludge handling is presented and briefly described, with most attention paid to the EU Sewage Sludge Directive. Further, the chapter concentrates on the national legislation of the states in Baltic Sea Region, both EU and non-EU members. Many legal restrictions concerning different sludge handling possibilities are identified.

12.1 EU LEVEL LEGISLATION ON SEWAGE SLUDGE HANDLING

EU regulations concern the other states around the Baltic Sea except Russia and Belarus. The legal framework established by the European Union and regulating the ways of sludge treatment and disposal mostly consists of directives, which should be incorporated into the national legislation systems of the member states. In their final provisions, each directive gives national legislators a timetable for the implementation of the expected outcome (in case the directive sets out precise objectives, e.g. the Landfill Directive), and also reporting and communication rules.

The directives have been adopted during past two decades, which has resulted in the varying levels of strictness of their requirements. Several member states have already managed to substitute two or more laws designed to implement one directive. As a consequence, there are currently more stringent rules on sludge handling in some of the EU countries than in others, and thus there is an urgent need for revision, particularly of out-of-date directives.

The EU legislative acts affecting the treatment and disposal of waste water sludge as per 1 September 2011 are the following (in chronological order, according to the day of adoption):

Figure 12-1: Sludge landfilling is regulated.
Photo: Shutterstock.com/ Pedro Miguel Sousa

1. COUNCIL DIRECTIVE of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC) – **The Sewage Sludge Directive**
2. COUNCIL DIRECTIVE of 21 May 1991 concerning urban waste water treatment (91/271/EEC) – **The Urban Waste Water Treatment Directive**
3. COUNCIL DIRECTIVE of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) – **The Nitrates Directive**
4. COUNCIL DIRECTIVE of 26 April 1999 on the landfill of waste (1999/31/EC) – **The Landfill Directive**
5. DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 December 2000 on the incineration of waste (2000/76/EC) – **The Incineration Directive**
6. COMMISSION DECISION of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EU establishinga list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC in hazardous waste (2000/532/EC)

7. DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market (2001/77/EC) **– The Renewable Energy Directive**
8. REGULATION (EC) OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 October 2003 relating to fertilisers (Nr 2003/2003) – **The Fertilisers Regulation**
9. DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives (2008/98/EC) – **The Waste Framework Directive**
10. DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council (2008/105/EC) – **The Priority Substances Directive**

The different directives are presented below from more general to more specific ones. The most important specific directive is the Sewage Sludge Directive (86/278/EEC).

The Waste Framework Directive (2008/98/EC)

From the regulatory point of view, the *Waste Framework Directive* is the main general legal act influencing the handling of all types of waste, including sewage sludge, by calling member states to adopt measures that encourage the prevention and reduction of waste and its potential harmful effects. This directive's Article 4 confirms the waste management hierarchy, according to which preference has to be given to waste prevention followed by waste reduction, re-use, recycling, and energy recovery. It also establishes principles for the use and disposal of waste, waste management plans, approval procedures and monitoring.

Another important function of the *Waste Framework Directive* is providing the definition for the terms 'waste', 'biowaste', 'hazardous waste', and confirming the list of types of waste by the Commission Decision 2000/532/EC[1]. In the meaning of this directive, biowaste is biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, as well as comparable waste from food processing plants, which suggests that sewage sludge is not. Additionally, given the fact that sludge is not among any of the explicitly mentioned exceptions, it can be assumed that all the provisions of this directive are applicable to sludge – as well as other directives referring to 'waste', if not specified otherwise. It is also stated that directives specific to certain wastes (e.g. sludge) are applied additionally to the *Waste Framework Directive*. In its final provisions, the directive requires member states to create necessary national regulations in order to comply with it until 12 December 2010.

The Urban Waste Water Treatment Directive (91/271/EEC)

Figure 12-2: Laboratory measurements of sludge and soil are required in the Sewage Sludge Directive. Photo: Jan-Eric Luft, Entsorgungsbetriebe Lübeck.

As the name of the directive suggests, it regulates all the stages of a waste water treatment process, also sewage sludge handling to some extent. In Article 14, the directive confirms the principles of the *Waste Framework Directive*, stating that sludge shall be re-used whenever appropriate, but it does not specify any more precise requirements except that "disposal routes shall minimise the adverse effects on the environment". The same article prohibits sludge disposal to surface waters or dumping from ships and discharge from pipelines after 1 January 1999. The directive additionally obliges member states to establish secondary treatment of urban waste water by a process generally involving biological treatment with a secondary clarifier by 31 May 2005.

Article 16 of the *Urban Waste Water Treatment Directive* requires reporting on sludge disposal every two years: relevant authorities in the area via national level transmit information to the Commission. Member states were to implement the directive no later than 30 June 1993. [2]

The Sewage Sludge Directive (86/278/EEC)

This directive, despite regulating exclusively agricultural use[3], is the only sludge-specific legal act at the Community level, and also the most important one. The sludge from plants treating domestic and urban waste waters, from septic tanks, or other similar installations can be used in agriculture only in accordance with this directive. Also, the acceptable treatment methods of sludge used in agriculture are specified by Article 2 (b) as follows: biological, chemical or heat treatment, long-term storage or any other appropriate process that will significantly reduce fermentability of sludge and the health hazards resulting from the use of sludge. Untreated sludge is allowed to be used only if it is injected or worked into the soil, and this should be authorised by special conditions laid down by the member states.

The Sewage Sludge Directive contains limit values for heavy metal concentrations in the soil and in the sludge as well as the average annual load introduced into soil. None of these limit values may be exceeded.[4] Furthermore, the directive prohibits the use of sludge on grassland and soil under fruit and vegetable crops (with the exception of fruit trees). The directive's Annexes IIA and IIB describe the analysis rules (although, the directive does not state explicitly who should conduct the analyses): the sludge should be analysed every six months, or 12 months if the results do not vary significantly over the year; the analysis shall also cover the following parameters: dry matter and organic matter, pH level, concentrations of nitrogen, phosphorus and heavy metals.

The soil should be analysed to determine its pH value and concentrations of heavy metals only; the frequency of the soil analysis is to be determined by the member states themselves. It should be noted though, that not all of the analysed parameters directly limit the application of sludge – some are being conducted for information or further estimation purposes. Article 10 requires member states to keep up-to-date records on the quantities of the sludge produced and supplied for use in agriculture; its composition and properties; the type of treatment; the names and addresses of the recipients and places where the sludge is to be used; and the availability of such information for the authorities.

The directive leaves the national legislators an option of creating more stringent measures if needed. The member states were given three years to create the necessary laws for implementation of this directive (therefore, no later than 12 June 1989), and were obliged to report to the Commission at three-year intervals.

The Landfill Directive (1999/31/EC)

Generally, *the Landfill Directive* determines stringent operational and technical requirements for landfilling of waste, which complicates the option for storing sewage sludge at landfill sites. This legal act provides the measures and procedures to prevent and reduce negative effects on the environment as well as any resulting risk to human health from landfills, and defines different categories of waste (municipal/hazardous/non-hazardous/inert), landfills for each of them, a standard waste acceptance procedure, and a system of operating permits for landfills.

The directive states that the spreading of sludges (including sewage sludges) on the soil for the purposes of fertilization or improvement is excluded from its scope. It prohibits the acceptance of liquid waste to a landfill – yet it does not include sewage sludge to the category of liquid waste. *The Landfill Directive* also compels that the waste destined to the landfill disposal is treated; treatment, according to Article 2 (h),

[1] Amended in 2001 by several other decisions; consolidated version applies since 1 January 2002.

[2] Countries that joined the EU later had different deadlines for implementation, sometimes with longer transition periods; nevertheless, currently this as well as all of the rest of the directives mentioned in this chapter are successfully incorporated into legal frameworks of all EU member states in Baltic Sea region.

[3] More specific requirements concerning manufacturing of fertilizers from the sewage sludge, types and labeling can be found in EC Regulation 2003/2003 relating to fertilisers.

[4] However, the Directive allows member states to choose whether to lay down requirements for both maximum annual quantities of sludge applied to soil, while observing heavy metals concentrations in sludge and the annual average load concentrations, or just one of them

Figure 12-3: Concentrations of nitrates and hazardous substances are regulated in surface waters. Photo: Shutterstock/Chepko Danil Vitalevich.

means all the physical, thermal or biological processes, including sorting, that change the characteristics of the waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery.

Furthermore, the directive sets out that each member state should implement a national strategy to reduce the amount of biodegradable (defined as "any waste that is capable of undergoing anaerobic or aerobic decomposition", meaning sewage sludge too) waste going to landfills through separate collection, composting, biogas production or materials/energy recovery and recycling, not later than 2003. The strategy sets objectives of:

- not later than the 2006 reduction to 75% of the total amount of biodegradable municipal waste produced in 1995;
- not later than 2009 reduction to 50%; and
- not later than 2012 reduction to 35%.

The reporting obligation was set for every three years; also, the member states received two years to create the necessary laws for the implementation of this directive – not later than 16 July 2001.

The Nitrates Directive (91/676/EEC) and the Priority Substances Directive (2008/105/EC)

These two directives mostly influence the landfilling of waste. The former requires identification of Nitrates Vulnerable Zones (NVZ) by the member states. These zones are defined as areas where the water quality has or will exceed the EC drinking water standard in terms of nitrates concentration. This is defined in directive 75/440/EEC concerning the quality required of surface water intended for the abstraction of drinking water in member states. Action programmes should be established and implemented in the mentioned NVZs in order to reduce water pollution by nitrogen compounds; also, land application of fertilisers should be limited (taking into account characteristics of the zone).

The Priority Substances Directive sets out the limits on concentrations in surface waters of 33 hazardous substances of major concern to European waters. These include polyaromatic hydrocarbons (PAH) that are mainly incineration by-products and polybrominated biphenylethers (PBDE) that are used as flame retardants, as well as heavy metals limited by the Sewage Sludge Directive 86/278/EC (cadmium, mercury, nickel and lead, from which the first two are identified as priority hazardous substances), and eight other pollutants like DDT and some other pesticides. Thus, it requires designating the 'so-called' mixing zones adjacent to discharge points in watercourses, where concentrations of the priority substances are allowed to exceed the EU drinking water standard. This is defined in directive 75/440/EEC concerning the quality required of surface water intended for the abstraction of drinking water in member states.

The Incineration Directive (2000/76/EC) and Renewable Energy Directive (2001/77/EC)

The directive regulates waste incineration plants as well as plants specifically designed for sludge incineration. It also lays down the requirements for all emissions from these plants – air emissions, solid residues (sludge ash) and flue gas cleaning, waste water from flue gas cleaning (scrubber water) and leachate from ash deposit. Sludge incineration plants, according to this directive, must obtain an environmental approval from the authorities.

Member states were to determine penalties applicable for not following the regulations, and the directive's provisions apply to existing plants as from 28 December 2005. The national laws, regulations and administrative provisions necessary to comply with this directive, should have been established not later than 28 December 2002.

The Incineration Directive regulates together the incineration of municipal waste, hazardous waste and partially biowaste, excluding from its scope the incineration plants that treat only vegetable waste from the forestry, agriculture and food processing industries, as well as wood and cork waste. It does not urge for energy recovery meaning that the incineration directive is not in accordance with the hierarchy of waste management defined in the waste framework directive. However, the later adopted *Renewable Energy Directive (2001/77/EC)* creates a common outline in order to promote an increase in the contribution of renewable energy sources to electricity production.

Other regulations and standards

Under **REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals)** regulations, waste is not considered as a substance and therefore most obligations do not apply to waste, and to sludge in particular. Nevertheless, suppliers of chemicals must show that risks can be properly managed also in the waste stage of the life cycle. ECHA, the European Chemicals Agency, carried out a review of the waste and recovered substances guidance document, and adopted it in May 2010. Once recovered substances cease to be waste, they are again subject to REACH obligations[5].

The point at which waste 'ceases to be waste' has been a subject of long debates. According to Article 6 (1) and (2) of the *Waste Framework Directive*, certain specified waste shall cease to be waste when it has undergone a recovery operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

a) the substance or object is commonly used for specific purposes;

b) a market or demand exists for such a substance or object;

c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to the products; and

d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

To develop a series of standardised test methods to properly perform sludge utilisation and disposal, and to correctly fulfil the legal requirements in the EU, the **European Committee for Standardisation (CEN)** established the **Technical Committee 308 (TC308)** in 1993. CEN TC 308 deals with sludges and is in charge of the elaboration of standards for the analytical characterisation of sludges and codes of good practices for different uses and the disposal routes of sludges. European standards shall be introduced in the collection of national standards without change. Other related committees are **ISO/TC190** 'Soil quality'; **CEN/TC223** 'Soil improvers and growing media'; and **CEN/TC292** 'Characterisation of wastes'.

Recent legal developments

The most important current development from the perspective of sludge treatment is the amending process of the *Sewage Sludge Directive*. The **3rd draft** from 2000 proposes an almost complete revision of the directive: the most important new aspects deal with the introduction of precise requirements for defining **(1) advanced treatments or (2) conventional treatments**, mainly addressed to sludge hygienisation and odour reduction.

After advanced treatments, sludge could be used on pastureland for forage crops; arable land; fruit and vegetable crops that are in contact with the ground and are eaten raw; fruit trees; vineyards; tree plantations and reforestations; parks; green areas; city gardens; all urban areas where the general public has access; and land reclamation. The conventionally treated sludge could be used for such purposes only if applied by

Figure 12-4: The Sewage Sludge Directive regulates the use of sludge in agriculture. Photo: Shutterstock.com/Gerard Koudenburg

[5] In all EU countries, sludge is considered to be waste. However, there are differences regarding how the legal status of compost and sludge derived fertilisers is being interpreted. In Germany and Finland, if it fulfils the fertilisers laws, it is labeled as a 'waste product'; in Latvia and Lithuania it is labelled as a 'product' – a licensed organic fertilizer or compost. Thus, in these four countries, the products might be a subject of the REACH norms.

deep injection and provided that temporal limitations regarding grazing time, harvesting and public access are respected. After conventional treatment, the use of sludge in parks, green areas and city gardens would be forbidden, as well as any use in forests.

Also, the limit values of the 3rd draft for heavy metals are stricter than the current ones; new values are proposed depending on the phosphorus content. Differently from the current directive's provisions, limit values are proposed also for organic micropollutants and dioxins.

In 2010, the European Commission rejected the idea of separate legislation on biowaste management in the EU, and therefore new solutions supporting better biowaste treatment were to be addressed by revision of existing legislation, *the Sewage Sludge Directive* in particular. Thus, the 3rd draft partly lost its relevance and the recent **Working Document on Sludge and Biowaste** now proposes a three-tier legislative system that will distinguish:

1) The so-called product-quality compost or digestate (source segregated waste) which could be used on soil without further control and regulated by *the End of Waste Criteria for Biowaste.*
2) Sludge and biowaste used in agriculture, regulated by the *revised Sewage Sludge Directive* which would set minimum quality standards for it.
3) Biowaste and sludges of lower quality restricted for use to non-agricultural lands only, left solely for regulation by *national legislation.*

Concerning the new suggestions for revision of the *Sewage Sludge Directive*, the proposal to set limits of heavy metals concentrations depending on the phosphorus content has been preliminary rejected, as the limits should be general and not depend on one specific agronomic parameter. Additionally, further proposed restrictions include: the sufficient stabilisation of sludge (not to cause unreasonable odours), sanitisation, a ban on use of the sludge on water-saturated, flooded, frozen or snow-covered ground, and time periods between sludge applications.

The end-of-waste criteria, mentioned above, are under preparation with the first working document published in February 2011.

12.2 NATIONAL LEGISLATION ON SEWAGE SLUDGE HANDLING IN THE COUNTRIES OF THE BALTIC SEA REGION

This section includes the detailed examination of country-specific legislation in the Baltic Sea region, compared to the EU regulations. Taking into account similarities of their legislation, countries have been grouped as follows: 1) the three Scandinavian countries of Denmark, Finland and Sweden plus Germany, which has established the strictest requirements on sludge handling; 2) Poland and the three Baltic States of Estonia, Latvia and Lithuania; and 3) the two non-EU members in the region – Russia and Belarus.

The structure of the analysis of each country's sludge-related legislation is built on the following points:

- General environmental legal acts and competent authorities.
- Regulations on the agricultural use of sludge:
  - types of sludge covered
  - mandatory or preferred treatment methods
  - limit values for heavy metal concentrations, pathogens and organic compounds
  - maximum allowed quantities of sludge or specific element (e.g. total phosphorus) to be applied annually
  - surfaces on which the use of sludge is prohibited
  - sludge and soil analyses and their frequency
- Regulations on other uses of sludge, e.g. in forestry, landscaping, re-cultivation, green areas.
- Specific rules concerning incineration and landfilling of sludge.

Information on each group of countries has been collected in two comparative tables – one of heavy metals concentrations limit values, and one summarising the key points in the legislation – in order to better illustrate the similarities, differences and stringency level of the legal measures chosen by each country to regulate sewage sludge handling.

The more detailed analysis of each country's legislation can be found in a separate appendix of this publication.

12.2.1 Scandinavian countries and Germany

Table 12-1: Comparative heavy metal limits values when sewage sludge is used for agricultural purposes, established by the current legislation of Finland, Sweden, Denmark and Germany. In case a country has more than one legal act and they provide different requirements for heavy metal concentrations, the one that implements the Sewage sludge Directive was selected as the source for this table.

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
FINLAND (in sludge)	3	300	600	2	100	150	1 500	-
SWEDEN (in sludge)	2	100	600	2.5	50	100	800	-
DENMARK (in sludge)	0.8	100	1 000	0.8	30	120	4 000	25 gar-dening
GERMANY (in sludge)	10 (5)*	900	800	8	200	900	2500 (2000)*	-
EU directive 86/278 (in sludge)	20–40	-	1 000 – 1 750	16–25	300–400	750– 1 200	2 500 – 4 000	-
FINLAND (in soil, pH>5.8 (lime-stabilised 5.5))	0.5	200	100	0.2	60	60	150	-
SWEDEN (in soil)	0.4	60	40	0.3	30	40	100–150	-
DENMARK (in soil)	0.5	30	40	0.5	15	40	100	-
GERMANY (in soil)	1.5 (1)*	100	60	1	50	100	200 (150)*	
EU directive 86/278 (in soil, pH 6-7)	1–3	-	50–140	1–1.5	30–75	50–300	150–300	-
in g/ha/year								
FINLAND (annual average loads to land)	1.5	300	600	1	100	100	1 500	-
SWEDEN (annual average loads to land)	1.75	100	600	2.5	50	100	800	-
DENMARK (annual average loads to land)	Limit values are not provided by Danish legislation							
GERMANY (annual average loads to land)	Limit values are not provided by German legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

*For soils classified as light soils, a clay content of <5%, and with a pH 5–6.

Table 12-2: Summary analysis of the current Finnish, Swedish, Danish and German legislation on sludge handling and vs. EU regulation. MS = member state(s) of EU; --- = 'not specified'.

Aspect / Country	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic compounds limit values (agricultural use)	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/ landfilling
FINLAND	Digestion, lime stabilisation, or other method significantly reducing pathogen content	Forbidden	---	---	To be determined on the basis of soil quality and the nutrient needs of the cultivated crops	Sludge: 12 per year first year, then 4 per year. Soil: before first application	Ministry of Agriculture and Forestry Decision – same limit values as in agriculture +Arsenic	Collection, treatment and use of landfill gas. Incineration: preferable energy recovery.
SWEDEN	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	Allowed, if worked into the soil within 24 hours after being spread	---	---	Max. amount of total P: depending on the P-class of soil, and of total NH_4-N: 150 kg/ha/year	Sludge: 1, 4 or 12 per year. Soil: before first application	SEPA recommendations	Landfill: prohibited since 2005. Incineration: regional authorities' permits.
DENMARK	Stabilisation, composting, pasteurisation	Forbidden	No occurrence of *Salmonella*; fecal streptococci below 100 per gram	DEHP, PAHs (9), NPE, LAS	7 tonnes of dry matter /ha/year	Sludge: for heavy metals – every 3 months, org. compounds – annually. Soil: before first application	In forestry – if local councils allow; in green areas – pasteurised	---
GERMANY	---	Forbidden	---	AOX, PCB (6), PCDD/PCDF	5 tonnes of dry matter /ha/3 years	Sludge: for heavy metals, org. compounds – 2 per year. Soil: before first application, every 10 years	Prohibition of use on forest, silviculture and green areas	Only waste with less than 5 % of organic matter is accepted in landfill from 2005 onwards
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of unthreaded sludge (if it is injected or worked into the soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/EC). Incineration Directive (2000/76/EC)

12.2.2 Baltic states and Poland

Table 12-3: Comparative heavy metal limit values when sewage sludge is used for agricultural purposes, established by the current legislation of Estonia, Latvia, Lithuania and Poland.

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
ESTONIA (in sludge)	20	1 000	1 000	16	300	750	2 500	-
LATVIA (in sludge)	10	600	800	10	200	500	2 500	-
LITHUANIA (in sludge: I category / II category)	1.5/20	140/400	75/1000	1/8	50/300	140/750	300/2 500	-
POLAND (in sludge)	20	1 000	500	16	300	750	2 500	-
EU directive 86/278 (in sludge)	20–40	-	1 000–1750	16–25	300–400	750–1200	2 500–4000	-
ESTONIA (in soil)	3	100	50	1.5	50	100	300	-
LATVIA (in soil)*	0.5–0.9	40–90	15–70	0.1-0.5	15–70	20–40	50–100	-
LITHUANIA (in soil: sand, sandy loam / loam, clay)	1/1.5	50/80	50/80	0.6/1.0	50/60	50/80	160/260	-
POLAND (in soil: light / medium / heavy)	1/2/3	50/75/100	25/50/75	0.8/1.2/1.5	20/35/50	40/60/80	80/120/180	-
EU directive 86/278 (in soil, pH 6–7)	1–3	-	50–140	1–1.5	30–75	50–300	150–300	-
in g/ha/year								
ESTONIA (annual average loads to land)	150	4 500	12 000	100	3 000	15 000	30 000	-
LATVIA (annual average loads to land: sand, sandy loam / loam, clay)	30/35	600/700	1 000/1200	8/10	250/300	300/350	5 000/6000	-
LITHUANIA (annual average loads to land: sand, sandy loam / loam, clay)	100/150	7 000/ 10 000	8 000/ 12 000	50/100	2 000/ 3 000	10 000/ 15 000	20 000/ 30 000	-
POLAND (annual average loads to land)	Limit values are not provided by the Polish legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

* Latvian limit values for heavy metal concentrations in soil vary depending on the types of soil (sand/sandy loam, loam/clay) and its pH (5–6; 6,1–7 and >7), thus altogether there are six limit values for each heavy metal. In this table, they are presented as a range, from the lowest (which is for sand/sandy loam soils with pH 5-6) to the highest (for loam/clay soils with pH >7).

Table 12-4: Summary analysis of the current Estonian, Latvian, Lithuanian and Polish legislation on sludge handling and vs. EU regulation. MS = member state(s) of EU; --- = 'not specified'.

Aspect / Country	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic compounds limit values (agricultural use)	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/ landfilling
ESTONIA	Aerobic/anaerobic digestion, incl. composting; chemical or thermal treatment	Allowed only for landscaping and re-cultivation, if worked into the soil within 2 days after being spread	Fecal coliforms <1000 CFU, and no occurrence of helminth eggs in 1 litre	---	---	Sludge: 2,4,6 or12 times/year first year, then 4,3,2,1 per year next years. Soil: before the first application, + every 5 years	Landscaping and recultivation is governed by the same regulation as agricultural use, all rules apply.	---
LATVIA	Storage, anaerobic digestion, aerobic and lime stabilisation, composting, pasteurisation, drying at 100 °C	Defined by the regulation, but no usage specified	---	---	Max. amount of total P: 40 kg/ha/year, and of total NH_4-N: 30 kg/ha/year	Sludge: 1,2,3,4, or 12 times per year. Soil: before the first application	In forestry and land reclamation special provisions in same regulation + max. amounts; in green areas add. heavy metals limits.	Landfill: special provisions in same regulation as agriculture; Incineration: ---
LITHUANIA	Biological, chemical or thermal, long-term storage or other process significantly reducing health hazards	Forbidden, as well as sludge of III category or C class	*Escherichia coli, Clostridium perfringens,* helminth eggs and larvae, and pathogenic enterobacteria[6]	---	Max. amount of total P: 40kg/ha/year, and of total N: 170 kg/ha/year	Sludge: 1,4, or 12 times per year. Soil: before the first application, further – depends on results	Recultivation and fertilization of energy crops special provisions in the same regulation + max. amounts 100 t/ha/year	Landfill: (National Strategic Waste Management Plan) targets for reducing biowaste on landfills; Incineration: ---
POLAND	Stabilisation +biological, chemical, heat or other process significantly reducing health hazards	Forbidden	No occurrence of *Salmonella* in 100 g, as well as eggs of ascaris, trichuris, or toxocara	---	3 t/ha/year	Sludge: 2,3 or 6 times per year. Soil: before the first application	Any other use than in agriculture, green areas, recultivation, compost forbidden, + max. amounts 15 t/ha/year	Landfill: (Law on Waste) targets for reducing bio-waste on landfills; Incineration: ---
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of unthreaded sludge (if it is injected or worked into soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before the first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/EC). Incineration Directive (2000/76/EC)

[6] These parasitological parameters should be analyzed, albeit different limit values are provided for all of them, taking into account differentiation of sludge into 3 classes.

12.2.3 Russia and Belarus

Table 12-5: Comparative heavy metal limits values when sewage sludge is used for agricultural purposes, established by the current legislation of Russia and Belarus vs. EU regulations. Russia and Belarus use the same standards and are thus compared to the requirements established by the EU Sewage Sludge Directive.

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
RUSSIA (in sludge: group I / group II)	15/30	500/1 000	750/ 15 000	7.5/15	200/ 400	250/500	1 750/ 3 500	42131
EU directive 86/278 (in sludge)	20–40	-	1000–1750	16–25	300–400	750–1 200	2 500–4 000	-
RUSSIA (in soil, pH>5,5)								
Maximum permissible concentrations	-	6**	3*	2.1	4*	32/6*	23*	2
Tentatively permissible concentrations (sandy loam / clay)	0.5/2	-	33/132	-	20/80	32/130	55/220	55/10
EU directive 86/278 (in soil, pH 6-7)	1–3	-	50–140	1–1.5	30–75	50–300	150–300	-
in g/ha/year								
RUSSIA (annual average loads to land)	Limit values are not provided by the Russian legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

*values for mobile forms of elements
**value for mobile form Cr (III)

Table 12-6: Summary analysis of the current Russian and Belarusian legislation on sludge handling vs. EU regulations. MS = member state(s) of EU; N = nitrogen; --- = not specified

Aspect / Country	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic compounds limit values (agricultural use)	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/ landfilling
RUSSIA	Biological, heat treatment, aerobic stabilisation, long term storage, pasteurisation, composting	No specific provisions are mentioned	*Escherichia coli* >100/1000*, *Salmonella*, Helminth eggs and cysts of intestinal pathogenic protozoa	Organic matter >20%, total N >0.6% of DM, P_2O_5 >1,5% of DM	Max. amount of total N- 300 kg /ha/year; max amount of dry matter: heavy soils- 10 t/ha/5 years, light sandy soils-7 t/ha/ 3years	Sludge: undefined. Soil: before the first application of sludge	Allowed in industrial horticulture, green areas, in forests, for reclamation of land and landfills	Landfill: sludge is accepted to municipal solid waste landfills, no treatment required; Incineration: ---
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of untreated sludge (if it is injected or worked into soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before the first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/ EC) Incineration Directive (2000/76/ EC)

*for group I / group II of sludge

12.3 CONCLUSIONS

Three kinds of the sludge handling legislation exist in the countries of the Baltic Sea Region: EU-level directives and other legal acts; EU member states' laws created to implement the abovementioned directives; and standards and norms of non-EU countries. All of them can be studied depending on two aspects: the form in which the legal acts were adopted and the content of the requirement they carry. Whereas the significance of the requirements' content seems to be obvious, it is also important to take into account the form, or the type, of the legislative documents when assessing the legal restrictions.

National regulations implementing the EU directives and state standards of non-EU countries

Most of the EU member states' sludge regulations are created in order to implement the EU directives, the most important being the Sewage Sludge Directive. For this reason, they are similar in form and structure. Both the Finnish Decision and German Ordinance on the use of sewage sludge in agriculture explicitly exclude fertilisers of sludge origin from their scope. Swedish and Danish Orders are also very similar; however, Danish legislation has two laws regulating and controlling the use of sludge for agricultural purposes.

In the Baltic States, the picture is quite different: only the Estonian Regulation is structured similar to the Finnish Decision. Additionally, all of the three countries: Estonia, Latvia and Lithuania, regulate more than one way of sludge disposal in one legal document, which usually, except its use in agriculture, includes land recultivation, landscaping, use in green areas and forestry, and for the fertilization of growing non-edible crops. Latvian legislation directs all the provisions of the regulation to both sewage sludge and compost. In Poland, part of the sludge related requirements is included in the general Law on Waste, whilst the rest is covered by a specific decree on sewage sludge.

In Russia and Belarus, sludge legislation is shaped in a completely different way. Unlike the other countries of the region, Russian norms (State Standard GOST-R and Sanitary Norms SanPin) governing use of sludge in agriculture are not at the level of laws, regulations, orders or decisions; rather, they are labelled as 'state standards', which makes them more similar in nature to the European Committee for Standardisation (CEN) documents.

Restrictions and requirements for sludge treatment and disposal

The content of the restrictions posed by the legislation of the Baltic Sea Region countries on sludge handling can be divided into requirements common to all regulations, and to more specific requirements in the legislation of some or in only one country. The common restrictions usually concern:

Figure 12-5. Photo: Johanna Karhu, HELCOM.

- pre-treatment methods;
- limit values of heavy metals contained in sludge and in soil;
- the restriction on the choice of crops and surfaces where sludge is to be applied; and
- the control of legislative compliance.

Heavy metal limit values in both sludge and soil are the lowest in Scandinavian countries. In Sweden and Germany, **landfilling** of sludge is banned, whilst in Denmark and Finland it is very rare, although formally not a forbidden way of sludge disposal. Because of these factors, it is common to consider Scandinavian and German sludge regulations to be the most stringent. However, the Baltic States and Poland have, in turn, established concise and detailed requirements concerning, for example, **treatment procedures or surfaces on which use of sludge is not allowed.**

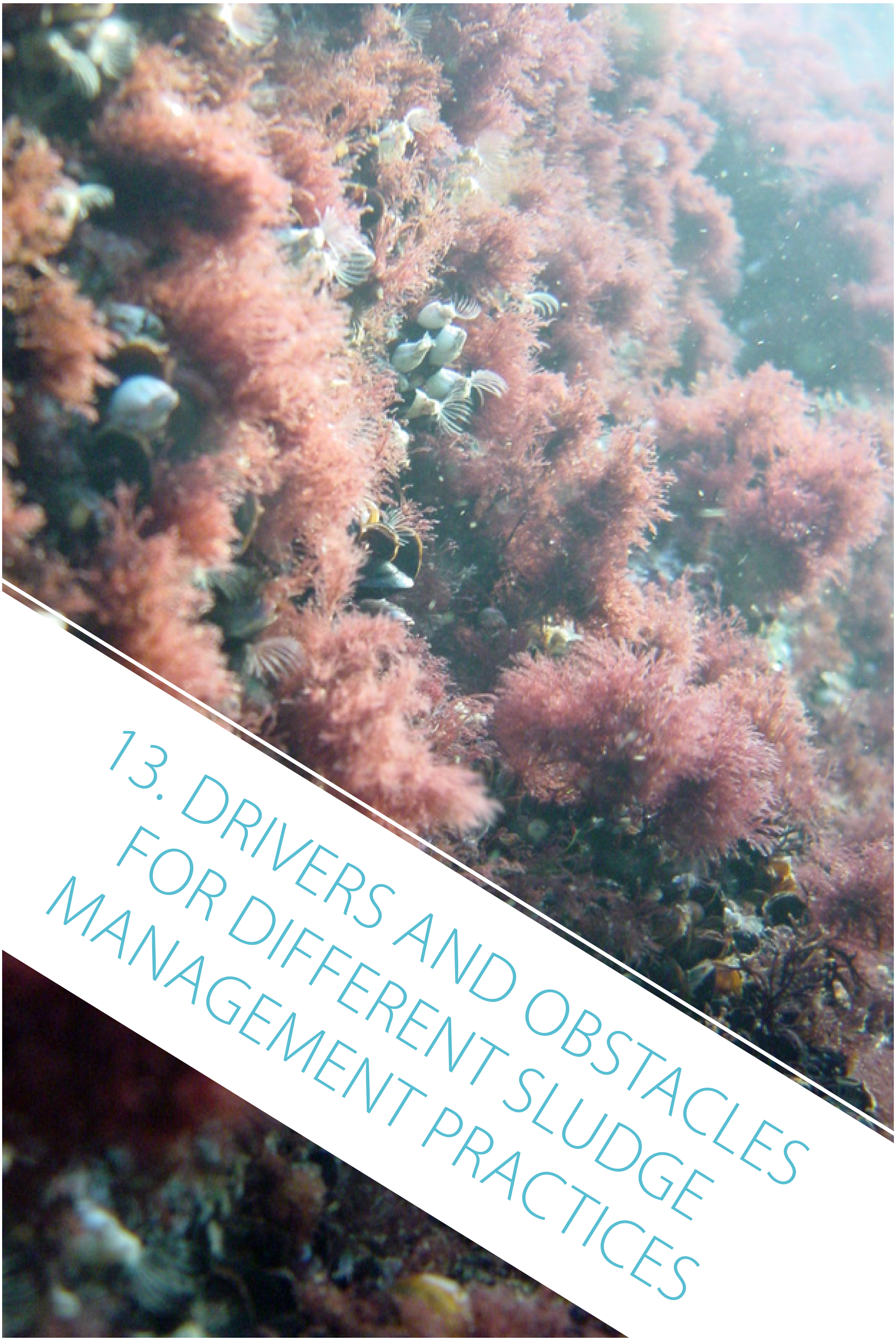
This makes sludge disposal more complicated, at least from the formal point of view. Russian norms are very similar in this sense to Polish and Baltic norms, providing even more elaborate methods for calculating the amounts of sludge that could be spread on agricultural soils.

The more specific requirements concern issues like **annual loads, surfaces where sludge is spread, or other than agricultural ways of disposal**. For instance, since the EU Sewage Sludge Directive allows both, only Denmark, Sweden and Poland have established maximum annual quantities of dry matter allowed to be applied to soil (7 tonnes/ha/year, 5 tonnes/ha/3 years and 3 tonnes/ha/year, respectively). The other countries have chosen to set up annual average loads of heavy metal concentrations. Although Russia as a non-EU state does not have to comply with this requirement, it has still established maximum annual quantities of dry matter: 10 tonnes/ha/5 years for heavy soils, and 7 tonnes/ha/3 years for light sandy soils.

The surfaces on which the application of sewage sludge is forbidden generally include grassland, and soil under fruit and vegetable crops. Moreover, most countries' legislation adds to the list of forbidden surfaces, such as national parks and protected areas, zones close to water bodies (in Latvian regulations, these are very precisely defined), flooded areas and wetlands, and frozen and snow-covered soils. **Geographically,** sludge application is limited only in Poland, where legislation states that sludge can be used for agricultural purposes only on the territory of the voivodeship (province) where it was produced. Regarding the **timeframe,** in general it is forbidden to apply sludge during the crop's vegetation period (in some countries, the periods between sludge application and the start of cultivation is explicitly defined). Lithuanian regulations state precisely when sludge cannot be applied, which is from 15 December to 1 March.

In most countries of the region, the use of sludge is permitted in the cultivation of non-agricultural crops, in forestry, green areas, recultivation or land reclamation, sometimes under the same heavy metal restrictions as agricultural use. Only German and Polish legislation forbids the use of sludge in forestry - the German Sewage Sludge Ordinance also forbids use of sludge in silviculture and green areas. In Denmark, only pasteurised sewage sludge can be used in green areas, and its application in natural forests must be sanctioned by the local councils.

13. DRIVERS AND OBSTACLES FOR DIFFERENT SLUDGE MANAGEMENT PRACTICES



Red algae, mussels and barnacles in the Baltic Sea. Photo: Samuli Korpinen, HELCOM.

The everyday choices and future challenges in sludge handling are not related to water management issues alone but are dependent on restrictions, incentives and policies in agriculture and energy, for example. The problems thus relate to wider policy guidance and governance. Waste water treatment plants in the Baltic Sea region, however, already have the possibilities to develop towards a modern biorefinery concept, producing renewable energy and recycling nutrients.

13.1 COSTS AND ECONOMIC INCENTIVES FOR SLUDGE HANDLING TECHNOLOGY OPTIONS

The costs of sludge management may be up to 50 % of the total running costs of a waste water treatment plant, and optimizing the sludge treatment and disposal may significantly contribute in the cost effectiveness of the water management as a whole (Starberg et al., 2005).

Costs for transport, disposal and the possible drying of the sludge are all directly dependent on sludge dewatering efficiency and the achieved dry solids content (see section 5.7 for details). It is thus recommended to calculate the dewatering result, energy costs and chemical costs in detail by pilot testing different options, and considering them in the decision-making and tendering processes.

The increasing costs of external energy sources together with feed-in tariffs and other support schemes for renewable energy are drivers for increasing anaerobic digestion and biogas production in waste water treatment plants. However, the main aim of digestion has been to stabilise the sludge; moreover, if the energy production is to be maximised, the individual processes should undergo further optimisation and development (Arnold, 2010). Although biogas production can also be enhanced with pre-treatment methods such as ultrasonic disintegration, these methods entail additional investments and running costs. Nevertheless, successful technical solutions can save money; for example, according to the estimations of Ultrawaves GmbH, ultrasonic disintegration was introduced at the Bamberg sewage treatment plant in Germany to destruct volatile solids saving some EUR 1.5 million because there was no need to build a new digester (Nickel, 2011).

Contradictory results emerge when comparing different solutions and taking wider environmental considerations into account. For example, life-cycle assessments have shown that incinerating sludge may be more expensive than other solutions, when greenhouse gas emissions and the net carbon footprint are included, despite savings in purchases of electricity and heating (Barber, 2009). The widely used anaerobic digestion, especially with advanced pre-treatment, has shown to have a very low carbon footprint; however, it may have problems with siloxane, sulphur or halogen impurities that corrode the equipment, or have unexpected process changes and instability (Arnold, 2010).

Also, the local possibilities for sludge disposal affect the costs of sludge handling at the treatment plant; in most cases, hygienisation is required of the sludge that is intended for agricultural use in the Baltic Sea Region. For composting as a sludge management option, land availability and thus the price of composting can vary significantly between countries and waste water treatment plants.

It may be possible to outsource sludge disposal from water companies to external actors in soil improvement or fertiliser production, or to energy companies in case of biogas.

Figure13-1. Photo: Shutterstock.com/Hraska.

13.2 HAZARDOUS SUBSTANCES AND SLUDGE QUALITY

Sewage sludge has to be stabilised and possibly hygienised to remove pathogens. In addition to pathogens, sludge contains many chemicals in small amounts. Heavy metals have been regulated for a long time in EU and national legislations, which has significantly decreased their amount in urban waste water sludge. Recently, there has been intensive discussion on organic substances that are present in urban waste waters and sludge which are classified as hazardous.

In the case of heavy metals, high concentrations of copper and zinc in the waste water often originate from households, whereas cadmium, chromium, mercury and lead mainly come from industry. The concentrations of heavy metals in sewage sludge have decreased in the last 20 years in many countries. In incineration, organic micropollutants are destroyed and the mercury is removed in the exhaust gas cleaning; however, the concentrations of all the other heavy metals increase, which may prevent direct fertilising with the ash from incineration. Some sources of mineral fertilisers have high concentrations of cadmium and uranium, which are not common in high concentrations in waste water sludge. (See chapters 9 and 11)

The organic chemicals in sludge mainly originate from households but to some extent also from industrial waste water if such are discharged to the treatment plant. These micropollutants might affect the use of sludge in soil improvement or nutrient recycling. Pharmaceuticals and flame retardants, for example, and their degradation or transformation products are numerous and the restriction or even monitoring of the individual substances is complicated and expensive. Among the Baltic Sea countries, Denmark and Germany have limitations for some organic compounds in the sewage sludge use in agriculture in their national legislation. Also Sweden has introduced standard limits for some organic compounds.

For evaluating risks there should be an estimation of the probability of harm caused by certain hazards, including the possible pathways from the source (e.g. the sewage sludge) to receptors in the environment or human population. Traditionally, the control of hazardous substances in effluents and sludge has been based on chemical analyses and by setting concentration limits on individual substances or substance groups. The issue becomes even more complicated as individual pollutants undergo physical, chemical and microbiological transformation, leaching and retention processes both during the sludge treatment and after application in the agricultural soil (Aubain et al., 2002). Some of the practices required for reducing pathogens if the sludge is applied on agricultural land (hygienisation, time restrictions and types of crops or surfaces) may also reduce the effects of the micropollutants.

There have been proposals for evaluating the combined effects and ecotoxicity of all of the potentially harmful properties more cost-effectively than based on single substance analyses, for example with a whole effluent analysis (WEA) that is applied with some industrial waste waters in Germany and Denmark. Wider use of the WEA for urban waste waters or sludges has been discussed within the project Control of hazardous substances in the Baltic Sea region, COHIBA (Nakari et al., 2011), and HELCOM's Monitoring and Assessment Group (HELCOM MONAS, 2011). EUREAU has commented on the WEA approach by emphasising source control, i.e. preventing the substances entering sewers and treatment plants. The WEA approach as such should be combined with chemical analyses to identify sources of hazardous substances and to plan preventive actions after finding a harmful effect in the sewage in question. COHIBA has produced guidance documents and recommendations for analysing and comparing different measures for reducing the emissions of certain hazardous chemicals from urban sewage cost-effectively (Mathan et al., 2012).

Usually, sludge incineration is favoured if the agricultural area where the sludge products could be spread is too limited or far away, or there is strong public resistance towards the use of sludge in agriculture. The discussion on organic chemicals in the sludge has also contributed to the low public acceptance for agricultural use (Aubain et al., 2002). Incineration destroys the hazardous organic chemicals and produces energy; however, the precious nutrients are lost to ash, which is usually defined as hazardous waste itself. The incineration plants also produce emissions to air, soil and possibly to water and require an environmental permit (see chapter 12). However, in countries where the agricultural or landscaping use of sludge is important, there has been long tradition in ensuring that the quality of sewage coming to the treatment plant already fulfils some requirements. If incineration is favoured, there is no such incentive to ensure the quality of the sludge in the first place.

13.3 RECYCLING OF PHOSPHORUS AND DISPOSAL OF SLUDGE

For decades the crucially important phosphorus was discarded to waterways with inadequately treated sewage. Since the 1970-80s, the municipal waste waters have been treated more and more efficiently in the Baltic Sea region. However, the nutrients separated from the waste water flow have not been reused efficiently. To increase the efficiency of phosphorus recycling it needs to be perceived not only as a polluting substance but as a recoverable resource in different policies. More efficient recycling of phosphorus would also help to reduce the phosphorus loading to the environment.

The global use of fertilisers increased six-fold between 1950 and 2000, and phosphorus concentrations in ecosystems increased at least 75 % (UNEP, 2011). The phosphorus is transferred first from the mines to the chemical industry and thereafter as fertilizer products – 90 % of phosphates worldwide are used in agriculture – to agriculture and cultivated fields: as grain, vegetables and meat to the food industry; as food products to markets; to consumers to be eaten and finally to sewage. There are huge system losses of phosphorus as 80 % of it is lost between the mine and the household.

There are already ongoing efforts to reduce phosphorus losses in agriculture, for instance by improving soil quality and preventing erosion. At the same time, increasing population and changing diets with increased meat and dairy product use lead to increased demand of phosphorus worldwide (Schröder et al., 2011). Thus, an increase in both the efficiency in phosphorus use and its recovery for reuse are important and need to be developed. The EU aims to reduce the dependency on phosphorus: both reducing loss (efficiency) and increasing recycling (recovery); phosphorus is already defined as a priority resource (EEA, 2011).

Today, over 40 % of sewage sludge in the EU is spread on land (Milieu, 2008); however, part of it is not taken up by plants and recycled since the phosphorus is bound to iron or aluminium salts that dissolve slowly (Schröder et al., 2011). National fertiliser legislation or the Common Agriculture Policy (CAP) terms on subsidies for farmers may require a certain level of solubility of the phosphorus in a product that is meant to be used as a fertiliser or soil improvement agent. All the phosphorus recovery technologies are still in the pilot or demonstration phases and are experiencing some technical problems so they are not yet economically feasible – the only examples in the Baltic Sea region are in Germany (see chapter 11). It is unlikely that an individual water company in the region would further develop products and change the chemical form of the phosphorus in the sludge, for example by releasing it from iron to a more soluble compound. However, there have been proposals to introduce economic instruments to increase the recyclability of phosphorus – for example by taxing or banning the use of iron as precipitant in treatment plants (Schröder et al., 2011). This, however, conflicts with the stringent phosphorus removal requirements and environmental objectives to drastically reduce phosphorus loading to the vulnerable Baltic Sea and the watercourses in its drainage area.

It is important for a water company (or a group of water companies) to study the situation of the local markets for compost or other sludge products before starting to produce them, not only for agricultural use but for landscaping, land reclamation and green areas. Another detail is that there might be different terms and conditions for fulfilling fertiliser requirements and to have permission to spread the actual product on the land. This should not be the water company's concern, because usually the spreading on land is outsourced to other actors such as farmers; however, it can have an effect on the market situation.

Among the Baltic Sea region countries, the sludge disposal strategies differ: in Finland and Estonia, over 80 % of the sludge is composted and used in landscaping or green areas; in Latvia and Lithuania, over 30 % is used in agriculture; in Germany, over 50 % is incinerated (Milieu et al., 2008). Landfilling is in use in some countries to a small extent; however in Sweden, Poland and Estonia over 10 % of the sewage sludge is currently being landfilled. The amount of organic waste for landfilling will be restricted, and the landfilling of waste water sludges and composted sludge products will practically be banned in the EU in the near future. Thus other disposal possibilities must be developed. In the non-EU countries of the region, sludge lagoons or landfilling are still a commonly used sludge disposal method, although such sludge handling methods as incineration, anaerobic digestion and composting are also in use or planned to be implemented in many waste water treatment plants. National energy policies have a great effect on the affordability of each method.

There has been a proposal to develop an EU phosphorus and food security directive with economic instruments like taxes for phosphorus losses and funding for recovery and recycling (Schröder, 2011). There are also national objectives (see chapter 11.1), for instance in Sweden to recycle 60 % of municipal waste water phosphorus by 2015. There is also industrial interest: ICL Fertilizers Europe, the biggest producer of phosphate and potassium fertilisers, is planning to use recycled phosphorus as 10–15 % of its raw material (SCOPE, 2012; ICL Fertilizers Europe, 2012).

Figure 13-2. Photo: Minna Pyhälä, HELCOM.

13.4 LEGISLATIVE FRAMEWORK – EU DIRECTIVES AND NATIONAL LEGISLATION

The current common restrictions on the possible ways of sludge handling and disposal usually concern pre-treatment methods, the limit values of heavy metals contained in sludge and in soil, the restriction on the choice of crops and surfaces where sludge is to be applied, and control of legislative compliance (see chapter 12). A wide collection of EU level decrees regulate the sludge management and disposal in eight of the nine countries around the Baltic Sea.

Sewage sludge is defined as waste under the EU's waste framework directive. The urban waste water treatment directive has, in turn, prohibited sludge disposal to surface waters, or dumping from ships and discharge from pipelines since 1999. Also, the sludge shall be re-used whenever appropriate and the disposal routes shall minimise the adverse effects on the environment.

However in agriculture, the sludge from urban waste water treatment plants can be used only in accordance with a third directive, the sewage sludge directive. Here, the acceptable treatment methods of sludge used in agriculture are specified – as biological, chemical or heat treatment, long-term storage or any other appropriate process that will significantly reduce the fermentability of the sludge and the health hazards resulting from its use. A fourth directive concerning landfilling prohibits the acceptance of liquid waste to landfill; also, the amount of biodegradable waste including sewage sludge going to landfills should be reduced through separate collection, composting, biogas production or materials and energy recovery and recycling. The incineration directive regulates sludge incinerating plants, requiring an approval from the national environmental authorities and regulating all emissions from the plants. Besides these five, there are also other directives that have an impact on municipal sludge management concerning the regulation of chemicals, for example.

The most important development of legislation has recently been the amending process of the Sewage Sludge Directive. The 3rd draft from 2000 proposed an almost complete revision of the directive. It would have introduced precise requirements for defining advanced or conventional treatments, mainly to sludge hygienisation and odour reduction. In 2010, however, the European Commission rejected the idea of separate legislation on bio-waste management in the EU and so the 3rd draft partly lost its relevance. There is now a recent Working Document on Sludge and Bio-waste. It proposes a three-tier legislative system that will distinguish the product-quality compost (or digestate), sludge and bio-waste used in agriculture, as well as bio-waste and sludges of lower quality restricted for use on non-agricultural lands only.

There are differences in the current national legislation among different Baltic Sea countries – heavy metal limit values, for example, are the most stringent in Scandinavian countries and Germany. There are detailed requirements on treatment procedures or restrictions on surfaces where sludge spreading is prohibited in Estonia, Latvia, Lithuania (Baltic States) and Poland. For sludge use in agriculture and landscaping, there are limitations on surfaces where the application and timeframes of sewage sludge is allowed. Also, in the Russian GOST and SanPiN state standards, which are also applied in Belarus, there are similar treatment- and surface-bound requirements and regulations like in the Baltic States.

Figure 13-3. Photo: Shutterstock.com/Ersler Dmitry

13.5 POLITICAL GOVERNANCE AND OTHER REGULATORY PRACTICES

Besides directives, the European Union has also other governance instruments. Another international actor is the intergovernmental Baltic Marine Environment Protection Commission (HELCOM) that implements wide-scale policies and recommendations based on an ecosystem approach to improve the state of the vulnerable marine environment and to reduce pollution. As Russia is also a contracting party of HELCOM, all the nine coastal countries are committed to implementing HELCOM policies.

The Baltic Sea is especially vulnerable to nutrient loading compared to other European marine areas. One of the most important duties of the Helsinki Commission is to make Recommendations on measures to address certain pollution sources or areas of concern taking into account Baltic regional specifics. These Recommendations are to be implemented by the Contracting Parties through their national legislation. Since the beginning of the 1980s HELCOM has adopted over 260 HELCOM Recommendations for the protection of the Baltic Sea, out of which 120 are currently valid[7].

Expectations for a possible HELCOM recommendation on sustainable sludge management (see section 1.2) would be setting the minimum sustainable outcome of sludge handling processes regardless of specific technical solutions at different treatment plants. Setting guidelines or aims for streamlining and harmonising the various detailed requirements for the use of sludge products – for example in agriculture – would be an improvement to the current situation. This sustainable sludge management framework could also include recommendations on encouraging small-scale electricity production, the further recycling of phosphorus by using sludge products in agriculture, as well as risk assessment guidelines related to hazardous substances in the sludge.

It is easier and more cost-efficient to reduce inputs at source than with end-of-pipe technologies. It has been estimated that one third of the phosphorus in household sewage could be reduced by introducing phosphate-free detergents, and that detergents comprise even up to 25 % of the average phosphorus loading (Swedish Chemical Agency, 2010). In laundry detergents, phosphates are usually substituted by polycarboxylic acids and clay-like zeolites. In some

Figure 13-4. Photo: Jannica Haldin, HELCOM.

Baltic Sea countries, the use of phosphorus-free detergents is common – HELCOM adopted a Recommendation 28E/7 for the substitution of polyphosphates in detergents in 2007 (HELCOM, 2007). The European Parliament backed in December 2011 an almost complete EU ban[8] on phosphorus in domestic laundry detergents from June 2013. Similar restrictions for domestic dishwasher detergents will likely apply from January 2017. The amount of sludge has been estimated to rise due to an increased use of zeolites; however, the use of phosphorus-precipitating chemicals decreases when the phosphorus concentration in the untreated sewage decreases. The actual outcome of these regulations remains to be seen.

The Blueprint to Safeguard Europe's Water is an EU policy response to overcome the challenges met with reaching good ecological status of the European waters by 2015, required by the Water Framework Directive adopted in 2000. The Blueprint will, for instance, introduce water-related green infrastructure measures, a consistent approach for the internalisation of costs from water use and water pollution, tackle water

[7] http://www.helcom.fi/Recommendations/en_GB/front/

[8] Regulation (EU) No 259/2012 of the European Parliament and of the Council of 14 March 2012 amending Regulation (EC) No 648/2004 as regards the use of phosphates and other phosphorus compounds in consumer laundry detergents and consumer automatic dishwasher detergents Text with EEA relevance.

efficiency and identify barriers to innovations, and be released by the end of 2012 (EC, 2012).

The European Federation of National Associations of Water and Waste Water Services EUREAU has published its position concerning the Blueprint (EUREAU, 2012). One of its eight focus areas concerns sustainable sludge handling and emphasises that sludge should be treated as a resource – a source of nutrients and energy. However, according to EUREAU the lack of a unified regulatory framework causes a lack of confidence among operators and entails a lack of funding. As the EU Sewage Sludge Directive review has been postponed, a clear legal tool to support sludge organic recovery is missing. EUREAU's view is that within the EU Waste strategy and Waste Framework Directive, the current discussion on the 'end-of-waste' (EoW)[9] status is an opportunity for some sludge-based products like composted sludge to be recognised as a useful fertiliser when achieving high-quality criteria. It could be an incentive to improve the quality of recycled sludge and so enhance its image and acceptability. The End of Waste criteria should also focus on the output, through specification on final product quality rather than by prohibiting input materials as sludge.

[9] http://ec.europa.eu/environment/waste/framework/end_of_waste.htm

Figure 13-5. Photo: Johanna Karhu, HELCOM.

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APPENDIX

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