HANDBOOK FOR SEWAGE SLUDGE OPERATORS

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Foreword

The purpose of this handbook is to provide support to all those involved in decision-making and day-to-day management of sewage sludge. The handbook is intended for those who already work with waste water treatment plants, as well as those who do not have a day-to-day job in this area but have to take decisions on the management of sewage sludge.

The purpose of the handbook is to provide as specific recommendations, practical examples and useful information as possible in a simple and comprehensible way for all its users.

The handbook was developed on the basis of the technical solutions and economic calculations included in the national planning document "Sewage Sludge Management Strategy in Latvia" (project), resulting from an analysis of the situation and an evaluation of the project "Implementation of River Basin Management Plans of Latvia towards good surface water status" (LIFE18 IPE/VL/000014 – LIFE GOODWATER within the framework of the IP and included in the reports drawn up by the project, which are fully available on the project's home page (www.goodwater.lv):

- An assessment of the existing situation regarding the volume, quality, recycling and use of sewage sludge in Latvia (2021).
- Study on waste water sludge treatment technologies used in Latvia (2021).

The handbook has been developed taking into account the experience of the work of Latvia's leading experts in the field of sewage sludge management, various national and international reports and technical and scientific publications on the management of sewage and sewage sludge developed so far.

The handbook provides information on wastewater and sewage sludge management techniques, treatment and recycling technologies, various possible alternative solutions to ensure the management of high quality, economic and environmentally friendly sewage sludge.

A separate chapter deals with the possibilities for the disposal of sewage sludge, which is essential for the planning and implementation of sludge treatment or recycling processes, as well as with the purchase and operation of technological equipment.

The handbook provides an insight into the binding regulatory enactments in force, as well as information on which authorities are involved in the processes of the monitoring, control and management of sewage sludge.

Abbreviations used

BOD (BOD_5)	biochemical oxygen consumption; biochemical oxygen consumption (five-day period); expresses the amount of oxygen consumed by micro-organisms over a period of five days by oxidizing water pollution
PE	people equivalent
CKS	centralized sewer systems
EU	European Union
KSS	sewer pump station
COD	chemical oxygen consumption; expresses the amount of oxygen required for the oxidation (incineration) of all pollution in water
LR	Republic of Latvia
LWWWWA	Latvian Water and Wastewater Works Association
LVĢMC	Latvian Environment, Geology and Meteorology Centre
MK	Cabinet of Ministers
WWTP	wastewater treatment plants
SV	suspended solids; expresses the amount of solid suspended solids in water that can be separated by filtering with a specified density filter; after drying to constant weight, the weight of the substances remaining on the filter is measured
SPS	service provider regardless of its legal status and form (local government, local government authority, merchant, etc.), which provides public services of water management
2-W	LVGMC National Statistical Report "2-Water. Overview of the Use of Water Resources", which is used by public service providers and not only by providing information on the amount of drinking water and effluent consumed during the year; Ii addition, the statistics shall include information on the amount of sewage sludge generated and disposed of during the year
VVD	State Environmental Service

MK Regulations No. 34 – Cabinet of Ministers of the Republic of Latvia Regulation No. 34 of 22 January 2002, Regulations Regarding Issue of Pollutant Substances in Water.

MK Regulations No. 362 – Cabinet of Ministers of the Republic of Latvia Regulation No. 362 of 2 May 2006, Regulations Regarding the Use, Monitoring and Control of Wastewater Sludge and its Compost.

Terminology

Agglomeration	Populated areas or parts of separate areas within their borders where the population, population density and economic activity are sufficiently concentrated to provide an economic basis for the establishment of a centralised sewer system for the collection and discharge of wastewater to or to the point of final discharge of wastewater treatment plants.
Activated sludge	An assembly of micro-organisms capable of removing wastewater from pollution contained therein under specially adapted conditions (mainly in oxygen-rich water, but also in a non-oxygen environment in major wastewater treatment plants).
Biochemical oxygen consumption	BSP_5 describes the amount of dissolved oxygen that the bacteria consume by oxidising the organic matter in the water sample.
Biological waste	Biodegradable waste of gardens and parks, waste of households, offices, catering establishments (restaurants, canteens, etc.), food and kitchen waste of wholesale and retail sites and other similar waste of food industry businesses (Section 1 of the Waste Management Law).
Biologically distributable (degradable) waste	Any waste which may decompose anaerobically or aerosol, such as food and garden waste, paper and paperboard (Article 2(m) of Directive 1999/31/EC), including sewage sludge.
Biological wastewater treatment plants	Wastewater treatment plants where wastewater treatment is carried out using biological processes, ensuring a reduction in the concentration of biodegradable substances.
Bioreactor	The part of the wastewater treatment plant where the effluent is treated with the activated sludge.
Hazardous substances	Substances or mixtures which, in accordance with Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on the classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC and amending Regulation (EC) No. 1907/2006, are to be classified in one of the hazard classes listed in this Regulation.
Sludge treatment	Sludge treatment means any manipulation of sewage sludge which, in principle, does not alter its structure and does not create a product which can be used for any valid purpose. Sludge treatment also includes dewatering or mechanical mixing of any kind of sludge.

Sludge recycling	Sludge processing means sludge manipulation which changes their structure and allows the production of a product which can be used for any valid purpose. Sludge recycling includes treatment in sludge fields, harvesting for biogas, composting, arson and also disposal at landfills. Recycling also includes technologies that are not yet in use in Latvia (pyrolysis and others).
Sludge disposal	Tthe use of sludge tip, such as agriculture, greening, etc.
Sludge management	A set of processes involving the treatment, recycling, etc. of sewage sludge operations to be carried out with sludge from the time they were found to recycling.
Digested	Nutrient-rich material resulting from the decomposition of organic substances in anaerobic biogas production reactors.
Emissions	Direct or indirect discharge of substances, vibrations, heat, non-ionizing radiation or noise from a stationary or diffuse source into the air, water or earth.
Floculant, coagant	Chemical compounds used in wastewater treatment and wastewater sludge dewatering processes to induce small particle joining in larger flakes, thereby improving the efficiency of wastewater treatment and effluent sludge dewatering processes.
Fugate	Liquid rich in nutrients and nitrogen compounds, occurring during digested welling or dewatering.
Compost manufacturer	Legal or natural person using sewage sludge for compost (MK Regulation No. 362)
Chemical oxygen consumption/ ĶSP	An indicator that describes the total amount of potassium dichromate required for oxidation of organic substances in water. Other reagents, such as chlorides, are added to the sample when testing.
Excess biologics /activated sludge	Sludge to be removed from the treatment of wastewater with activated sludge, as the mass of activated sludge has increased in excess of the amount required by the process.
Large WWTP	WWTP designed with wastewater treatment capacity exceeding 1000 m^3/dn.
Small WWTP	WWTP designed with wastewater treatment capacity below 1000 m^3/dn.
Mezophile anaerobic sludge processing	Removal of sewage sludge from biogas reactors at approximately 35 °C.
Mineralized or contaminated sludge	Sludge treated after removal in the effluent treatment process for mineralizators or thickeners to increase the proportion of dry matter to 2–4 %.

Wet sewage sludge (dehydrated sludge)	Treated sewage sludge using one of the types of sludge treatment specified in MK Regulation No. 362. Depending on the method of sludge treatment performed by the WWTP operator, sludge may contain 75 – 95 % of water and 5–25 % of dry matter.
Unwrought sludge	Sewage sludge which has not been subject to any of the treatment of sewage sludge specified in MK Regulation No. 362.
Sewage sludge	Colloidal residues resulting from the treatment of municipal, municipal and manufacturing wastewater in treatment plants, as well as from septic tanks and other similar wastewater treatment plants.
Wastewater sludge compost	A product of decomposition of sewage sludge and various vegetable materials (peat, leaves, straw, sawdust and other materials) (MK Regulation No. 362).
Producer of sewage sludge	A legal or natural person managing wastewater treatment plants whose technological processes result in sewage sludge (MK Regulation No. 362).
Project LIFE GOODWATER IP	Project "Implementation of River Basin Management Plans of Latvia towards good surface water status" (*LIFE18 IPE/LV/000014 – LIFE GOODWATER IP*).
Primary sludge	Sludge obtained by the guise of special guidelining wastewater which has only passed the stage of mechanical pretreatment.
Polluting activity	The use of soil, subterranean, water, air, equipment or buildings and other fixed facilities, which may cause environmental pollution or risk of accidents, as well as activities carried out in a contaminated site, which may cause the spread of pollution.
Pollution	Direct or indirect discharge of substances, vibrations, heat or noise caused by human action into air, water or land, which may have a harmful effect on human health or the environment and which may cause damage to property or affect the use of natural resources and other lawful use of the environment.
Contaminated site	Soil, subterranean depths, water, sludge, and buildings, production plants or other objects containing polluting substances.
Potentially contaminated site	Soil, subterranean depths, water, sludge, and buildings, production plants or other objects containing or likely to contain polluting substances after unverified information.

Municipal waste	Municipal waste is considered the unsorted waste that is distributed waste collected from households, including paper and paperboard, glass, metals, plastics, biological waste, wood, textiles, packaging, electrical and electronic equipment, battery batteries, large-size waste, including mattresses and furniture, as well as unsorted waste and waste from other sources. collected waste with characteristics and composition similar to the waste from households. Waste from manufacturing, agriculture, forestry, fisheries, septic vessels and sewerage network and treatment plants, including sewage sludge, end-of-life vehicles or waste generated in works and demolition of works (Section 1 of the Waste Management Act), shall not be considered as municipal waste.
Wet sludge	Sewage sludge, which is naturally formed and untreated, is removed from the organic wastewater treatment process. Sludge contains 99 % water, 1 % dry matter.
Strategy	Sewage Sludge Management Strategy in Latvia (project), 2021.

Introduction

Wastewater and sewage sludge management is an essential aspect of the services provided by water management. Given that sewage sludge is inevitably generated in the wastewater treatment process, its management cannot be separated from the collection and treatment of waste water.

In the context of international sustainable development policy planning documents, sewage sludge is a resource whose return to production processes is essential and necessary. Taking into account the characteristics of sewage sludge, it can be both a source of nutrients and a biomass for the generation of renewable energy.

The recycling of sewage sludge in order to obtain agricultural fertilizers as an alternative to chemical fertilisers is an ongoing challenge. As a result of biological processes of wastewater treatment, substances separated from wastewater accumulate in sewage sludge, such as phosphorus and nitrogen, which are found in high concentrations. At the same time, sludge from municipal wastewater treatment plants is characterised by low levels of pollution, which is one of the prerequisites for the use of the composting method and for the production of fertilisers for agricultural use.

If sludge quality analyses confirm its compliance with the quality indicators laid down in the legislation, it may, after processing, be used for the enrichment of agricultural or forestry land with plant nutrients by incorporating both sludge and compost prepared from it into the soil.

The development of wastewater treatment and sludge recycling technologies may increase the possibilities for the use of sludge, including for the recuperation of renewable energy sources, degraded areas, the installation of permanent plants and other forms.

It is essential that the wastewater sludge management process is simple, economically justified, in compliance with the requirements specified in regulatory enactments. Accordingly, it is important that recycled sewage sludge is safe for the environment, does not cause or transfer pollution to the environment. This would ensure that sludge is a permanently demanded and accessible resource.

Adequate management of sewage sludge can contribute to the achievement of the objectives of the EU Sustainable Development Initiative, particularly in the circular economy.

Legal framework

The management of sewage sludge, like any process identified by the EU as essential and necessary for society, is limited, described and regulated by different levels of regulatory framework[1].

Hierarchy and Explanatory Notes to EU legislation

Regulations	Regulations are legally binding acts. They should be fully applied in all EU Member States.
Directives	The directives are legislation, which sets targets to be achieved by all Member States. However, each Member State is entitled to draw up its own package of measures to achieve them.
Decisions	Decisions shall be binding on specific addressees (e.g. an EU Member State or company) and directly applicable.
Recommendations	The recommendations are not legally binding.
Opinions	Opinions are instruments enabling institutions to express their views without imposing any legal obligations on their addressees.

Binding laws and regulations

The European Green Course (2019) states that, by 2050 at the latest, all greenhouse gases will be neutralised, with Europe becoming the first part of the climate neutralisation world, while economic growth will be decoupled from resource use.

Major European Union directives

- Council Directive 2000/60/EC (23.10.2000) establishing a framework for Community action in the field of water policy (Water Framework Directive).
- Council Directive 2006/118/EC (12.12.2006) on the protection of groundwater against pollution and deterioration.
- Council Directive 98/83/EC (03.11.1998) on the quality of drinking water.
- Council Directive 86/287/EC of 12 June 1986 on the protection of the environment, in particular soil, in agriculture using sewage sludge (Directive 86/278/EC). (*Only recycled sewage sludge shall be allowed to be used in agriculture in order to significantly reduce pathogenic contamination and control heavy metals pollution by*

[1] https://europa.eu/european-union/law/legal-acts_lv

imposing restrictions on where sewage sludge and their compost are not to be used in agriculture).

- Council Directive 91/271/EC of 21 May 1991 on the treatment of urban wastewater (Directive 91/271/EC).

Major regulatory enactments of the Republic of Latvia

- The Law on Public Service Regulators (07.11.2000).
- The Law on Water Management Service (18.06.2015).
- Pollution Act (15.03.2001).
- MK Regulation No. 174, Regulations on the Provision and Use of Public Water Management Services (22.03.2016).
- MK Regulation No. 34 "Provisions on the emission of pollutants into water" (22.01.2002). These provisions take over the requirements of Directive 91/271/EC.
- MK Regulation No. 1082 "Procedures by which Category A, B and C polluting activity permits are to be applied for and permits to perform Category A and B polluting activities shall be issued" (30.11.2010).
- MK Regulation No. 362 "Provisions on the use, monitoring and control of sewage sludge and their compost" (02.05.2006). These rules take over the requirements of Directive 86/287/EC. *(They specify the quality requirements for sewage sludge and its compost, as well as the procedures for recording the quality, quantity and use of sludge, the requirements for temporary storage of sludge, as well as for disposal at landfill sites).*
- The requirements for preparing and submitting the "Regulations on Official Environmental Protection Statistics and Pollutant Activity Review Forms" of MK Regulation No. 271 shall be laid down for the preparation and submission of the water resource use report "2-Water".

1. CURRENT SITUATION IN LATVIA

1.1. National wastewater sludge management strategy

Document "Sewage Sludge Management Strategy in Latvia", 2021, was developed as part of the "Implementation of River Basin Management Plans of Latvia towards good surface water status" (*LIFE18 IPE/LV/000014 – LIFE GOODWATER IP*) project. The commissioning party for the development of the strategy is LWWWWA, but it was developed by IsMade, in cooperation with LWWWWA's specialists and in consultation with the Latvian Ministry for Environmental Protection and Regional Development. The draft strategy can be found on LWWWWA's website[2].

The strategy is a national strategic planning document describing and analysing the situation in the wastewater sludge management sector and, taking into account the EU and national legislation and policy planning documents, identified challenges, as well as administrative, environmental, economic and technically relevant and feasible solutions and their costs, establishing action to achieve a single sector further development.

Vision

All sewage sludge in Latvia has been properly recycled and used in an environmentally safe manner, in accordance with the principles of the circular economy.

Mission

The establishment of a sewage sludge management system which recycles sewage sludge as a permanently demanded and accessible resource is an essential part of the circular economy, while the process of collecting and processing sewage sludge is simple, environmentally sound, economically justified, well-defined and supervised.

Objectives

1. **The management of sewage sludge is well regulated, environmentally sound and economically justified.**
2. **The wastewater sludge management process is simple and supervised.**
3. **Recycled sewage sludge is a permanently demanded and accessible resource.**

In order to achieve the objectives pursued, the strategy has chosen the option that wastewater sludge management is carried out by the SPS. The wastewater sludge management model requires each local government to take a decision on the management of sewage sludge in the area of the municipality responsible, while providing support for the establishment of an adequate wastewater sludge treatment and recycling infrastructure for the SPS. The PSOs determined for the management of sewage sludge shall ensure that in the territory of the local government, Category 1–4 sewage sludge generated in the WWTP provision of public water management services is concentrated in the largest WWTP of the municipality, where its initial

[2] https://www.lwwwwa.lv/projekts-life /

treatment (mechanical dewatering) is carried out, certain municipalities may also have several dewatering sites. PSOs responsible for sewage sludge shall deliver all collected and dehydrated sewage sludge from the largest WWTP to the nearest of the 26 wastewater sludge recycling centres. On the other hand, wastewater sludge recycling centres shall ensure that the recycled sewage sludge is properly tested after being treated for 12 months (cold fermentation) or composting before being incorporated into the soil, quality certificates are produced and accurate information in the national statistical reports is provided.

In line with the mission and vision included in the strategy and with the objectives and tasks defined for their implementation, a plan for the implementation of the sewage sludge strategy has also been drawn up, including measures, costs and the responsible authorities for each task.

The strategy is to be implemented by 2028, when the results achieved will be evaluated, and to be revised in line with the current situation.

1.2. Wastewaters and their volume in Latvia between 2017 and 2019

According to the information collected and analysed on the treatment of wastewater and the management of sewage sludge respectively, it should be concluded that in Latvia sewage sludge is generated from 921 (Figure 1) from 967 in the register of the LVĢMC with a biological wastewater treatment cycle. The analysis does not include WWTP for which the information available in the register is repeated or WWTP in which the actual amount of effluent is so small that the amount of sewage sludge cannot be calculated and is almost zero or zero. A full assessment of the situation, analysing the management of sewage and sewage sludge, is included in the report entitled "Assessment of the existing situation regarding the volume, quality, recycling and use of sewage sludge in Latvia (2021)", which is available on the website of[3] *LIFE GOODWATER IP*[3].

[3] www.goodwater.lv

Figure 1. Placement of 921 biological BUILDINGS in Latvia gathered in 2020

The total amount of wastewater treated for 921 WWTPs was 111.7 million m^3 in 2017, 98.1 m^3 in 2018 and 100.2 m ^{3} in 2019. During the period included in the data analysis, the difference between the largest and the smallest annual amount of wastewater is 13.6 million m^3 or 12 %, which is a significant difference and can be compared to the three-year amount of wastewater treated in Daugavpils. The reason for such significant differences is largely the changing weather conditions and the amount of rainwater entering the waste water collection system. Thus, wastewater treatment plants are exposed to higher levels of wastewater, but the concentration of pollution is lower than that of typical municipal wastewater, and therefore the overall differences in pollution to be treated are not so significant.

However, the inflow of rain water into WWTPs has a significant impact on the WWTP processes and their effectiveness (especially in small WWTPs), so that in order to ensure continuous, high-quality and efficient wastewater treatment in the long term, it is necessary to minimise the flow of rain water into WWTPs.

For the transparency of the situation, all 921 WWTPs are divided into five groups. The division is based on the actual wastewater flows over one year (m^3/year). All WWTPs are grouped using the actual flow rates in 2019, which describe the average actual effluent flow rate (Table 1 and Figure 2).

Table 1

Number of WWTPs and the Volume of Actual Effluent Flow Rate in 2019[4]

Group	Actual effluent flow rate, m³/year	Number of WWTPs	Total number of WWTPs, %	Total flooded wastewater, m ³/year	Total amount of wastewater streamed, %
R	>6 000 000	1	0.1	49 697 469	49.6
A	500 000–6 000	21	2.3	32 673 644	32.6
B	100 000–500 000	32	3.5	7 465 228	7.4
C	20 000–00 000	148	16.1	5 784 224	5.8
D	<20 000	719	78.0	4 600 519	4.6
TOTAL		**921**	**100**	**100 221 084**	**100**

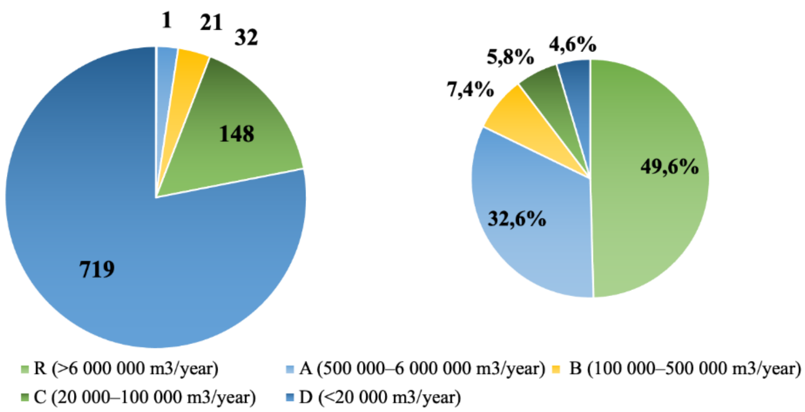


Figure 2. Division of wastewater treatment plants into groups by number and proportion of total wastewater in the wastewater treatment group in Latvia

The data gathered show that approximately half of Latvia's economic wastewater is treated in one WWTP (WWTP "Daugavgrīva"), which is located in Riga and treats wastewater from Riga and its local governments, which are locating wastewater in the centralised wastewater collection network of Riga. Wastewater from the municipalities of Ropaži, Ķekava, Salaspils, Ādaži and Mārupe, as well as Jūrmala, flows into this WWTP.

Group A comprises 21 WWTPs with an actual wastewater flow rate between 0.5 m^3 and 6.0 m^3 in 2019. The actual flow rate of wastewater in Group A accounts for 32.6 % of the total amount of wastewater analysed. 22 WWTPs or 2.4 % of the total number of WWTPs in Groups R and A purify 82.2 % of the total estimated amount of wastewater, which is a significant part

[4] https://www.meteo.lv/lapas/vide/udens/udens-statistics-aggregates/2-udens-parskati/2-udens-parskati? id = 1104 & nid = 434

of the total amount of wastewater in Latvia. However, 867 WWTPs or 94.1 % of the total number of WWTPs in Groups C and D purify 10.4 million m^3 of wastewater per year, or only 10.4 % of the total amount of wastewater, but despite the relatively small amount of wastewater, their geographical location and distribution throughout the territory of Latvia indicates the need to ensure adequate wastewater treatment processes in order not to create extensive and regional risks to environmental pollution.

1.3. Volume of sewage sludge in Latvia between 2017 and 2019

The primary objective of the wastewater treatment processes is to ensure that the effluent discharged is as clean as possible and complies with the requirements for the permitted pollution of effluent laid down in the legislation. It is typical of the biological wastewater treatment processes used for the treatment of economic wastewater, which are carried out in 921 WWTPs in Latvia, that unnecessary activated sludge is inevitably generated, which needs to be removed from the wastewater treatment process and must be properly processed, recycled, and disposed of. The amount of generated sewage sludge depends on the number of internal (selected wastewater treatment technology, process scheme, etc.) and external factors (air and wastewater temperature, incoming wastewater composition, etc.), but this cannot be an end in itself, e.g., by regulating WWTP processes to minimize the amount of sewage sludge generated, the extent, the effectiveness of wastewater treatment is significantly affected and potential risks to environmental pollution are created.

None of the WWTPs should have a priority objective of producing as much or less sewage sludge as possible, risking a potential deterioration of the effluent pollution rates discharged. In order to ensure that appropriate wastewater treatment processes are carried out in WWTPs, there may be and there are significant differences between WWTPs with the amount of wastewater sludge generated by a similar amount of inflows, formed in the sewage treatment process and accurately listed after discharge. It should be noted that the amount of wastewater sludge generated is recorded in the wastewater sludge removed during the treatment process, or sludge, which has developed in the biological treatment process, thereby creating too high levels in the biological wastewater treatment process and reducing the effectiveness of wastewater treatment.

The amount of wet sewage sludge (1 % dry matter) has been calculated based on the information contained in the “2-Water” report on the actual annual amount of wet sludge (5–25 % dry matter) and the corresponding dry matter content in sludge for each WWTP of the years 2017–2019 (see Table 2 and Figure 3).

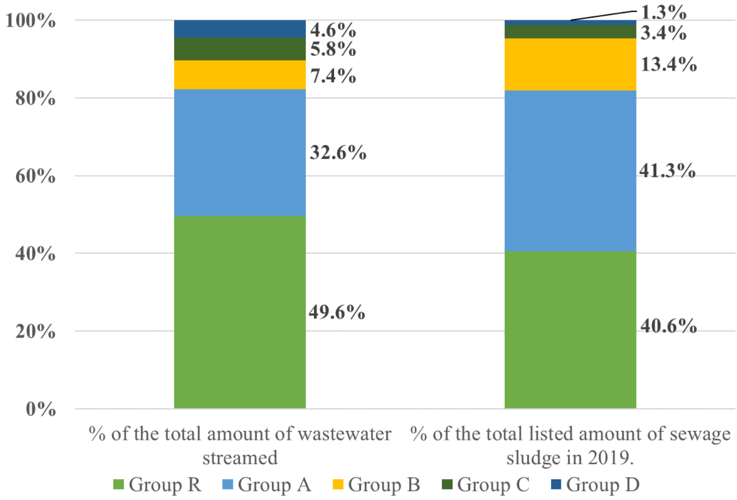


Figure 3. Comparison of the amount of effluent and effluent sludge produced by different WWTP groups

Table 2

The Amount of Sludge Listed by the WWTP Operators as Specified in Statement "2-Water" in 2017–2019

Group	Amount of wet 1% sewage sludge in 2017 t/year	Amount of wet sewage sludge 2018 t/year	Amount of wet 1% sewage sludge in 2019 t/year	Total amount of sewage sludge listed in 2019, %
R	843 436	837 329	914 023	40.6
A	946 074	942 959	930 268	41.3
B	415 522	446 636	302 369	13.4
C	58 497	58 693	77 579	3.4
D	36 047	28 890	28 690	1.3
TOTAL	**2 299 576**	**2 314 507**	**2 252 929**	**100**

The total amount of wet sewage sludge generated in Latvia is approximately 2.25 cal million tonnes per year.

By appropriately treating nearly half of all wastewater in Latvia, a large part of the amount of generated sewage sludge is generated by the WWTPs of Group R, which represents approximately 40 % of the total amount of wet sludge generated. This is related to the differently organised wastewater treatment process, in which part of the pollution contained in wastewater is treated by primary guideliners, which reduces the total amount of sewage sludge generated by the wastewater treatment process.

For the WWTPs of Group A, the total amount of wet sewage sludge generated is approximately 41 % of the amount of all wet sewage sludge generated in Latvia during the year, although the total amount of effluent is 32.6 %. Consequently, during the year, the WWTPs of Groups R and A produce approximately the same amount of wet sewage sludge, which is slightly less than 1 million tonnes per year. If the amount of waste water treated by Groups R and A is 82.2 % of the total amount, it means that they generate 81,9 % of wet sewage sludge.

For Group D with 719 WWTPs, the total declared amount of wet sewage sludge produced is only 1.2 % and is considered to be insignificant. It is concluded that 54 WWTPs of Groups A, B and R in total produce 95.3 % of the total amount of wet sewage sludge produced in Latvia during a year.

On average, the production of 1 m^3 wastewater sludge requires 44 m^3 wastewater

The results obtained from the analysis of the data allow to draw the following conclusions:

1) The amount of sewage sludge generated by wastewater treatment processes depends directly on the capacity of the WWTP – the bigger the WWTP, the less the amount of sewage sludge is generated by the treatment of one m^3 of wastewater.
2) The statistical data and their accuracy for small WWTPs are worse than the data on large WWTPs because the smaller wastewater treatment plants with a lower amount of wastewater actually effluent, the lower the amount of sewage sludge, the more inaccurate is the control and accounting of the amount of sewage sludge generated. It results in statistical data which do not correspond to the actual situation.
3) In small WWTPs, the efficiency of wastewater treatment and sewage sludge management is lower – the smaller the WWTP and the lower the centrally collected wastewater system is, the more uneven is the wastewater flow (including rain water), which results in treatment plants being more frequently subjected to different variations in the technological process and for WWTPs, sewage sludge may be leached (during increased rain water inflows) or dies (insufficient amount of wastewater and reduced content of organic matter).
4) Statistical data reflecting the amount of sewage sludge in WWTPs of Groups C and D may be inaccurate. A significant number of individual and small WWTPs charge excess sludge for removal, dewatering and treatment in the large (most commonly Group A) WWTPs, therefore they do not count the amount of wastewater sludge generated and the amount of the generated sludge is included in the amount that is generated in the large WWTPs.

The average amount of effluent actually treated in Group D of WWTPs is ~6 400 m^3/year. Average production of wet sewage sludge is ~40 m^3/year. This is a very small amount, which can theoretically be dispersed in nature during a short period of time, stored in non-compliant containers for several decades, or by other activities, resulting in statistical data showing that in most of the small WWTPs sludge does not occur, which does not actually correspond to the technological processes. According to report "2-Water", only 331 (46 %) of all 719 WWTPs in Group D have generated excess sludge during the year. And only 131 (18 %) of the wastewater sludge generated during the year exceeds the average of 40 t/year.

Calculation of theoretical increase in sewage sludge

Using the "2-Water" report data on the amount of wastewater flow and the concentration of pollutants in each of 921 WWTPs, the amount of wet sewage sludge generated in theory has been calculated, both in each WWTP and in Latvia as a whole. According to the WWTP group described above, a comparison was made between the theoretically calculated and actual statistical amount of sewage sludge (Figure 4).

According to the previous findings, the highest relative difference between the theoretical increase in sewage sludge and the amounts included in the statistical reports has been found in the relatively smaller wastewater treatment plants in Groups C and D. The reasons for these differences are mentioned in the previous conclusions. A substantial difference has also been observed for the WWTPs of Group A, which could be due to significant changes in the composition of wastewater and individual cases where statistical reports have been incorrectly completed.

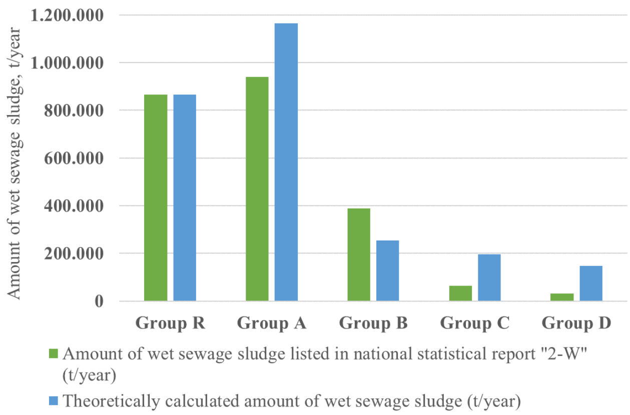


Figure 4. National statistical report "2-W" listed and theoretically calculated the amount of wet sewage sludge (t/year) in different groups of WWTPs, on average, over the period 2017–2019

1.4. Quality of sewage sludge in Latvia

In accordance with the regulatory framework in force in the European Union, the requirements for the quality of sewage sludge shall be incorporated into national regulatory enactments. The requirements for the quality of sewage sludge in Latvia are included in MK Regulation No. 362 on the use, monitoring and control of sewage sludge and its compost, which specifies the requirements only for indicators of heavy metals and their concentration in sewage sludge and compost. The above-mentioned rules of Cabinet of Ministers distinguish five classes of sewage sludge quality, the first of which is the highest but the fifth – the lowest. In the case of agrochemical, pathogenic or organic pollutants, sludge quality classes are not defined, but certain agrochemical indicators (soil pH) are taken into account when deciding on the use of the corresponding amount of sewage sludge in agricultural land.

The figures on agrochemical, microbiological and heavy metals of Latvian sewage sludge have been studied and described in the study carried out by association LWWWWA "Assessment of the existing situation regarding the volume, quality, recycling and use of sewage sludge in Latvia (2021)" within the framework of *LIFE GOODWATER IP* of 2021, available on the project's home page. As part of the study, the characteristics of sewage sludge in 2020 are analysed in 21 residential wastewater treatment plants representing potential wastewater sludge quality indicators.

The study assessed the quality of the sewage sludge of the Latvian WWTPs according to the following criteria:

1) concentration of heavy metals;
2) agrochemical indicators;
3) concentration of hazardous substances;
4) residues of pharmaceuticals;
5) microbiological contamination.

Heavy metals

The determined concentration of heavy metals in the sewage sludge of Latvian wastewater treatment plants is small and the sewage sludge conforms to the quality Class 1 or 2 of sludge specified in Latvian legislation. There are some exceptions when the increased composition of heavy metals in sewage sludge may be linked to a possible inappropriate pretreatment of production wastewater prior to the discharge of production wastewater into the centralised wastewater collection network of the populated area.

Agrochemical indicators

The results of measurements of agrochemical effluent sludge show that sewage sludge is a valuable agricultural field fertiliser. On average, approximately 25 kg of phosphorus, 63 kg of nitrogen and 720 kg of organic matter are available in Latvia per 1 t of wastewater sludge dry matter. During a year, according to the data for 2017–2019, it corresponds to approximately 685 t of phosphorus, 1700 t of nitrogen and 19 470 t of organic matter. Agrochemical indicators show that sewage sludge is a valuable field fertiliser that contains both a significant amount of nitrogen and phosphorus for plants in a readily accessible form and a lot of organic substances that many Latvian fields badly need.

Hazardous substances

The concentration of hazardous substances found in sewage sludge during the study is very low, it is below the most stringent standards adopted in other EU countries (where they are defined, since there are no such rules in most EU countries). Therefore, it can be argued that the wastewater sludge in Latvia is relatively clean and its use in the circular economy can be relatively simple. On the basis that the Latvian legislation does not regulate the concentration of these and other substances dangerous to the aquatic environment in sewage sludge, such analyses are not carried out in the WWTPs of Latvia and the concentration of dangerous substances is not indicated in sludge quality certificates.

Pharmaceutical residues

The concentration of residues of pharmaceuticals in sewage sludge is very low, the active substances of certain antibiotics were not detected in any sample. These measurements also show the high quality of sludge in Latvia and the low risk of potential environmental pollution. It should be noted that only the residual values of antibiotic active substances in sewage sludge have been analysed during the study.

Microbiological contamination

The Latvian legislation does not limit the permissible microbiological pollution of sewage sludge, therefore such measurements are not performed in Latvian wastewater treatment plants and are not indicated in sludge quality certificates. Data from the study show that in Latvian wastewater treatment plants microbiological contamination of sewage sludge is higher than the permissible microbiological contamination in individual countries where it is limited. Not all EU countries limit microbiological pollution of sewage sludge or limit maximum levels of micro-organisms. The non-inclusion of such a requirement in the legislation is explained by the fact that recycled sewage sludge can be compared with manure and digestat, which also has an increased level of micro-organisms, used extensively in soil repairing and fertilising.

The quality of sewage sludge in Latvia is considered to be good and most of the sewage sludge complies with the sludge Class 1or 2 referred to in MK Regulation No. 363.

2. WASTEWATER AND ITS MANAGEMENT

2.1. Classification of wastewater

Wastewater occurs as a result of people's day-to-day work and economic activity. The majority, or 99.9 % of the wastewater composition, consists of water. The remainder is pollution, which determines the type of wastewater and its management methods. Depending on the origin of the wastewater and the nature of the pollution (physical properties, chemical and bacteriological composition), a distinction is made between municipal, manufacturing (industrial) and rain water (precipitation) (Figure 5).

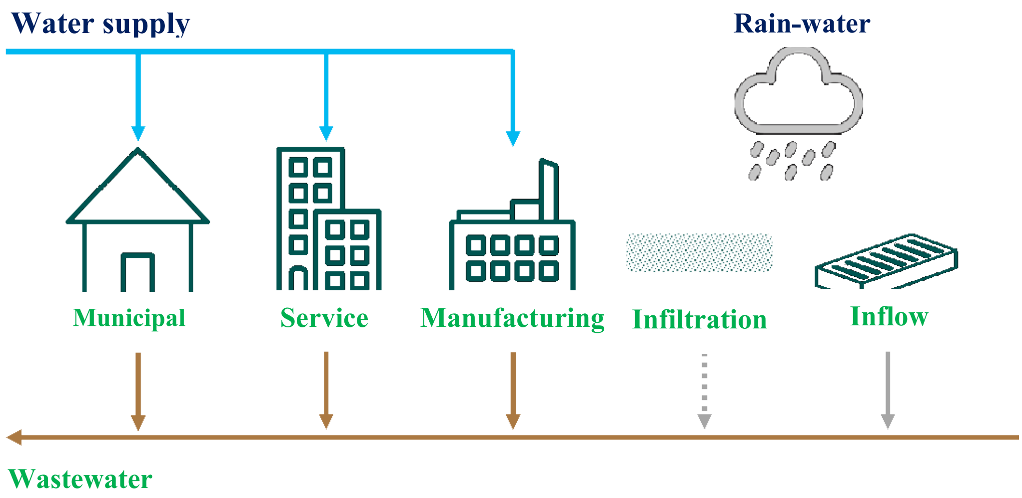


Figure 5. Wastewater sources in sewer systems

According to MK Regulation No. 34 on the emissions of pollutants into water, wastewater is water that has changed its original physical, chemical or biological properties due to human activity. Wastewater may also be classified and characterised according to its origin and composition as follows:

Municipal wastewater	Wastewater arising from public and residential buildings and public service facilities due to a variety of physiological, hygienic and household activities
Stormwater	Water formed from atmospheric precipitation by draining from building roofs, streets and other areas with full or partial surface
Production	Wastewater produced at business or production sites and not classified as municipal wastewater or wastewater
Urban/economic wastewater	Municipal wastewater, municipal and manufacturing wastewater mix and rain water

The composition of wastewater may vary greatly from one location to another. Mineral impurities (sand, clay particles, oils, acids, alkali, salts, etc.) and organic matter (municipal waste, faecal matter, vegetable oils, petroleum products, hair, vegetable fibres, etc.) are distinguished depending on origin (micro-organisms, mushrooms of yeast and mould, aquatic plants, etc.). These components may be in both solution and colloid and suspended form, which creates different sediments during the effluent treatment process and has a different impact on the purification process. Untreated or incompletely treated wastewater, by flowing into watercourses, water reservoirs and underground waters, contributes to their quality and sometimes makes water sources wholly or partly unusable.

2.2. Description of wastewater

The wastewater treatment process and the use of appropriate technologies are also significantly affected by its composition. The composition of wastewater pollution may be organic, inorganic and mixed. The most common organic contamination and its breakdown is shown in Figure 6.

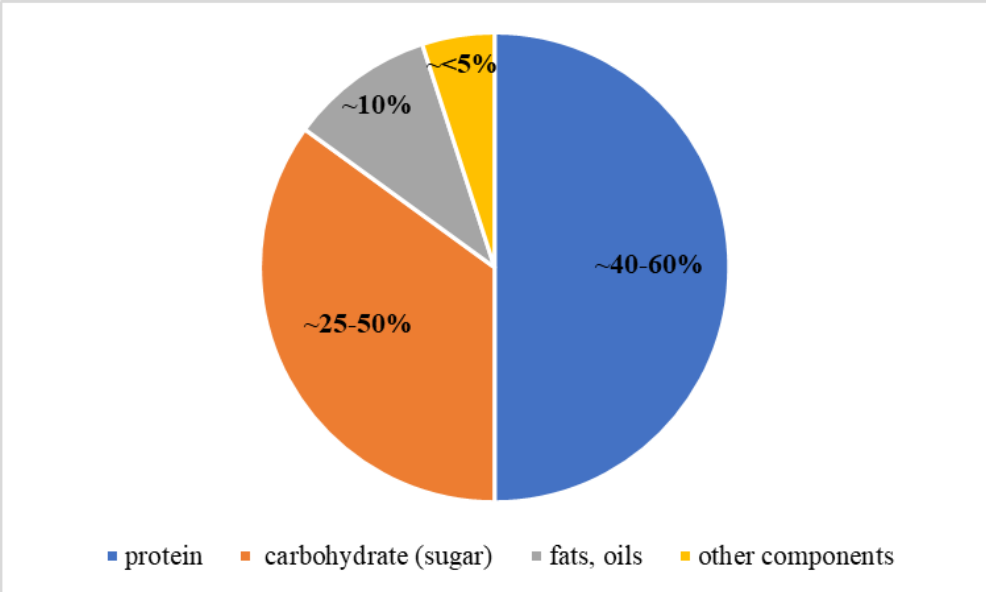


Figure 6. Organic pollution in wastewater

Inorganic contamination is present in virtually all effluent. Inorganic contamination is mainly composed of a variety of salts in water, largely determined by the amount of salts in the drinking water used, such as chlorides, sulfate, sodium ion, etc. However, inorganic pollution does not pose problems for WWTPs with biological purification plants.

2.2.1. Typical municipal wastewater

In accordance with the MK Regulation No. 34, a range of indicators for the concentration of pollutants has been established, which describe a typical level of municipal wastewater pollution (Table 3). It should be noted that during writing of the handbook there were discussions about changing individual concentration intervals. For typical municipal effluent characteristics, the corresponding wastewater composition should be observed in the intake of WWTPs in populated areas where the wastewater is daily only discharged to the population, there is a small percentage of infiltration and rain water, and all production wastewater discharged into the system is adequately developed prior to discharge in the wastewater collection network and successively in WWTP. However, it should be noted that the specified concentrations of pollutants are not applicable in all cases where only municipal wastewater is collected and purified, since their changes may affect the specific characteristics of wastewater collection networks, for example, very long collection networks may lead to the degradation of pollutants in wastewater under anaerobic conditions, which may also be affected by total composition changes, and habits of water use by the population of the area, such as saving water, lead to the discharge of wastewater with a higher concentration of pollution.

Table 3

Typical Characteristics for Municipal Wastewater

Substance	Concentration (mg/l)
Biological oxygen consumption (BSP_5)	150–350
Chemical oxygen consumption (COD)	210–740
Total suspended substances	120–450
Total phosphorus	6–23
Total nitrogen	20–80

The composition of wastewater may be judged by the concentration of its pollution prior to the intake effluent treatment plant. If the concentration of pollutants in the intake of WWTP is significantly higher than that of typical municipal effluent, it is possible that the wastewater collection network also leads to production wastewater which may not be controlled or pretreated, or other atypical wastewater, which does not have the characteristics of municipal wastewater. In such cases, it is advisable to evaluate the capacity of WWTP for the treatment of the wastewater concerned, as well as to identify potential sources of increased pollution.

WWTPs in populated areas are most often intended for the treatment of municipal wastewater, so that the treatment of different types of atypical pollution according to the "polluter pays" principle is the responsibility of their creators, such as production plants. The proportion of pollution in typical municipal wastewater is largely appropriate to be purified using organic wastewater treatment.

2.2.2. Industrial wastewater

In order to allow the discharge of production wastewater into a residential wastewater collection system, it is necessary to assess in detail the composition of the wastewater concerned, the chemical and biological compounds contained therein, the presence of hazardous and priority substances, the inadequacy of the flow and pollution, etc., which may have an impact on the effectiveness of the operation of the treatment plants. In some cases, notional contaminated wastewater may also be ineligible for drainage to a centralized sewer network because they find too low a concentration of pollutants, which in turn may lower the efficiency of WWTP. The production wastewater must undergo pretreatment, depending on the degree of contamination, before being discharged to centralized sewage networks and further treatment in municipal WWTP. In some cases, not only pretreatment is necessary, but also additional biological purification in order to significantly reduce pollution in the effluent of production.

If the wastewater of production is discharged into the centralised system for the collection and treatment of economic wastewater, the water management undertaking **shall enter into a contract with the production undertaking** regarding the drainage and acceptance of the wastewater of production in the centralized sewage system and subsequent treatment in the wastewater treatment plants.

The concentration of polluting substances in wastewater affects the safety and health of the employees of the water management company, the technical state of the sewer pipeline and the equipment of the wastewater treatment plants, the technologies for the treatment of wastewater and the process thereof, the quality of the sewage sludge, as well as the state of the water body where the effluent is discharged. These aspects should be taken into account when concluding an agreement with a water management company on the acceptance of wastewater from production for treatment and discharge into the environment.

Water management undertakings may, in accordance with the provisions of Regulation No. 174 of the Cabinet of Ministers of the LR, Regulations regarding the provision and use of public water management services, 14.04.2017, **for an additional fee**, permit the production undertaking to discharge wastewater from the centralised sewer system in which the permissible concentration of certain polluting substances is higher than that referred to in the relevant local government's binding regulations.

There are also situations where a single permit for a certain amount of wastewater is issued.

For the permanent discharge of elevated polluting wastewater into the collection networks of economic wastewater, the special provisions of the contract must specify the following:

1) substances intended to be emitted, including all priority substances and hazardous substances identified in wastewater or forecasted by the company to discharge;
2) the maximum permitted concentration of polluting substances, which depends on the capacity of the WWTP;
3) the additional fee specified by the service provider for the purification of those pollutants;
4) effluent discharge regime (estimated flow changes);
5) the amount of compensation if a higher concentration of polluting substances has been established in the survey of discharged production wastewater than specified in the binding regulations of the local government or in the contract;
6) procedures for sampling and quality checking;
7) exceeding the applicable compensation for the maximum quantity of pollutants authorised to discharge for each of the specified parameters.

Permit the discharge of production wastewater into a centralized system for the collection and treatment of economic wastewater and subsequently perform their treatment in WWTP only if:

1) emissions of purified wastewater from wastewater treatment plants do not have an adverse effect on the environment and do not cause non-compliance of accepting waters

with the requirements of Regulations No. 34 and other regulatory enactments of the MK;

2) sewage sludge could be managed in accordance with the requirements of regulatory enactments without causing damage to the environment.

When calculating the concentration of limiting and maximum permitted pollutants in the wastewater of production to be drained in the economic wastewater system, account must be taken of:

1) whether the concentration of polluting substances in the effluent entering wastewater treatment plants will not exceed the maximum concentration specified in the wastewater treatment technologies;
2) at which concentration the pollutant will remain in the wastewater after purification and whether the limit values set out in the permit for the polluting activity of category A, B or C will not be exceeded when the effluent is discharged into the water bodies;
3) that production wastewater flows and quality measurements must be carried out in an accredited laboratory prior to the conclusion of the contract.

It must be verified that the concentration of heavy metals in sewage sludge does not exceed the permitted concentration, so that sewage sludge can be used for the intended purposes after processing (agriculture, greening, etc.).

When allowing the production wastewater in wastewater treatment plants, it is necessary to ensure that it is regularly checked for quality in an accredited laboratory.

Effluent sludge from production

In order to ensure adequate wastewater quality before being released into a centralized sewage network or residential wastewater treatment plant or directly in the environment, most production plants use a physical-chemical wastewater treatment method called dissolved air flotation. This process forms the so-called flotation foams/sludge with the highest concentration of dissolved pollution in the effluent of production. It is the most widely used method in food companies. The composition of the flotation sludge heavily depends on the nature of the production, the range of products to be produced, and its composition differs significantly from the sewage sludge of domestic wastewater treatment plants. This type of sludge is most commonly passed on to biogas producers because it contains high-concentration organic substances.

Sewage flotation sludge **must not be mixed with sewage sludge** from domestic wastewater treatment plants, except when municipal sewage sludge is processed into biogas.

In some cases, production plants carry out a full-cycle biological wastewater treatment (required after dissolved air flotation) in order to be able to clean wastewater up to the limit values for pollutants specified in the legislation and the permit for polluting activity. Such biological wastewater treatment processes also result in excess biological sewage sludge, but the composition of this type of sewage sludge is also not typically predictable because it is still associated with the values of the generating wastewater pollutants to be assessed in each effluent treatment plant separately.

2.3. Wastewater treatment

According to the National Control Report[5], there were around 818 thousand households in Latvia in 2021, and about 185 thousand economically active companies, whose activities result in daily wastewater from both municipalities and production. Consequently, it is essential that both household and production effluent is properly treated in all centralised (Figure 7) and individual wastewater treatment plants.

Figure 7. Wastewater treatment plants in Liepāja with a design capacity of 55 000 m^3/dnn, "Liepāja Water" Ltd. archive

The environment and water resources are exposed to a variety of hazards, therefore it is important to take care of the protection of these resources and the reduction of pollution by identifying all sources of risk in order to avoid their harmful effects. Untreated wastewater not only affects the quality of water for drinking and household use but also influences the wellbeing of water bodies by reducing water transparency and destroying the various species in water bodies. The principled scheme of wastewater treatment plants is shown in Figure 8.

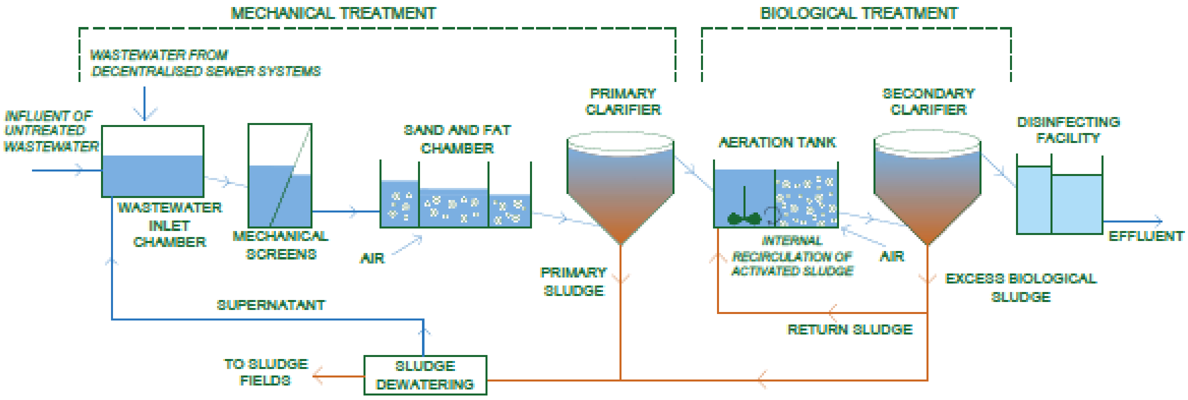


Figure 8. Principle scheme of the wastewater treatment plant

In order to ensure a successful wastewater treatment process, it is necessary to be familiar with the specific nature of the incoming pollution: the share of municipal wastewater in the total pollution load, what and how many industrial plants discharge their production wastewater into the centralised sewer and the specific nature of their production and the technologies for pre-treatment. It is also important to identify whether there are no additional environmental protection requirements for the water body in which the effluent is to be discharged or discharged and a specific level of contamination in the discharge of waste water treatment plants.

According to MK Regulation No. 34, wastewater **treatment technologies of centralised sewage systems are classified as follows:**

Appropriate treatment	➡	The utilisation of such technologies and drainage systems, which ensure the conformity of the accepting water body with the specified environmental quality objectives and other conditions referred to in the regulatory enactments regarding environmental protection
Initial/primary treatment	➡	Mechanical or chemical wastewater treatment or any other process in which the biological oxygen consumption of discharged effluent is reduced by not less than 20 % against incoming load and the total amount of suspended substances is reduced by not less than 50 % in relation to incoming load
Secondary treatment	➡	The use of technologies that primarily perform biological treatment with secondary settlement or use other processes that are able to ensure compliance of the quality of wastewater from treatment plants with the requirements specified in regulatory enactments

In accordance with the provisions of MK Regulation No. 34, in agglomerations where:

1) the human equivalent is less than 2000, all wastewater collected by centralised sewer systems shall undergo appropriate treatment, as well as ensuring a reduction of pollution in relation to incoming load in accordance with the requirements specified in regulatory enactments;
2) the human equivalent is between 2000 and 10000, all wastewater collected by centralised sewer systems shall undergo at least secondary treatment;
3) the human equivalent is greater than 10000, all wastewater collected by centralised sewage systems shall be treated more intensively by performing secondary treatment and shall ensure the conformity of wastewater with the requirements specified in these Regulations.

2.3.1. Technologies for the treatment of economic wastewater

2.3.1.1. Mechanical treatment of wastewater

The mechanical purification of wastewater is the separation of coarse particles, sand and other landfills, as well as floating substances by mechanical and simple physical means. The purpose of the mechanical effluent treatment is to remove non-dissolved substances, which make it difficult and interfere with future effluent treatment. Principle scheme of the mechanical treatment of wastewater is presented in Figure 9.

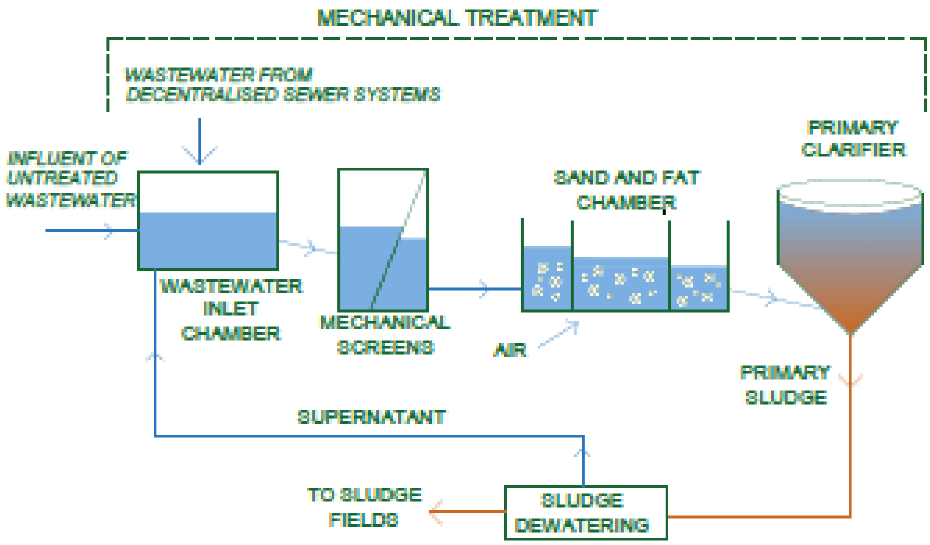


Figure 9. Basic scheme of the mechanical treatment of wastewater

The process of mechanical effluent treatment to dispose of sinking substances includes bars (Figure 10), sand pickers, fat pickers or volatile matter separators, and primary leeches. By mechanically cleaning municipal wastewater, it is possible to reduce pollution by 40–60 %. Following such purification, the concentration of mainly non-aqueous organic substances and micro-organisms is decreasing.

Figure 10. Mechanical bars at wastewater treatment plants in Liepāja, from "Liepāja Water" Ltd. archive

If the sand receiver has a high flow rate, it holds little sand, but if the speed is low, it holds a lot of organic matter.

2.3.1.2. Biological treatment of wastewater

Biological treatment of wastewater with activated sludge is the dominant waste water treatment technology worldwide. It is safe, capable of ensuring a sufficiently good treatment of wastewater from typical municipal wastewater pollution prior to release into the environment. Principle scheme of the biological treatment of wastewater is presented in Figure 11.

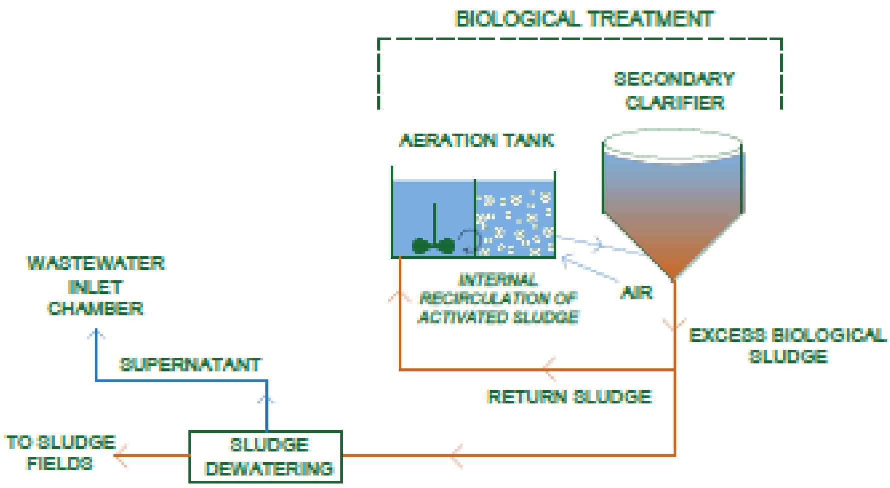


Figure 11. Principle scheme of the biological treatment of wastewater

The biological purification of wastewater is aimed at mineralising suspended and dissolved organic impurities found in wastewater. This occurs mainly through activated sludge in

$NO_3^- +$ $\rightarrow {}^1/_2 N_2 + a*CO_2 + b*H_2O + OH^-$

aerotanks (Figure 12) or by relatively simple installations, biofilters. Micro-organisms contained in active sludge consume wastewater pollution for the assurance of life processes, so that wastewater is treated. At the same time micro-organisms multiply, and the weight of activated sludge is increasing. Biological purification significantly reduces the presence of organic substances and nutrients in wastewater.

Figure 12. Aerotanks and secondary guidelines at wastewater treatment plants in Liepaja, from "Liepāja Water" Ltd. archive

Modern, well-regulated wastewater treatment plants provide a 90 % and even more reduction in pollutants such as suspended substances, biochemical and chemical oxygen consumption, total phosphorus and nitrogen pollution.

Reduction of nitrogen concentration

One of the most important tasks of biological wastewater treatment is the reduction of nitrogen levels. This happens in several stages using both aerobic and anaerobic bacteria. The process is based on the conversion of ammonium ions to nitrationes in the presence of nitrified bacteria (nitrification) and the subsequent reduction of nitrationes to free nitrogen (denitrification). The nature of the reduction in oxygen concentration is shown in Figures 13 and 14.

1.Stage $NH_4^+ + 1{,}5O_2 \rightarrow NO_2^- + 2H^+ + H_2O$

2.Stage $NO_2^- + 0{,}5O_2 \rightarrow NO_3^-$

3.Stage $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

Figure 13. Nitrification

$$NO_3^- + \text{organic matter} \rightarrow 0.5\,N_2 + a\,CO_2 + b\,H_2O + OH^-$$

Figure 14. Denitrification

Reduction of phosphorus concentration

It is essential to ensure that phosphorus is removed from wastewater in cases where there is a high phosphorus concentration or limited emission levels. Phosphorous compounds affect the growth of water plants, particularly algae, in open water bodies where effluent is discharged. Phosphorus concentration may be reduced in both biological and physical chemical way (Figures 15 and 16).

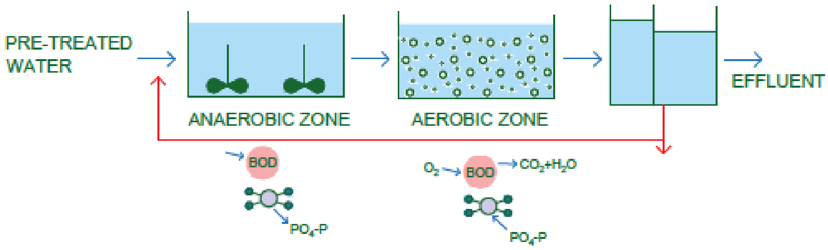


Figure 15. Biological removal of phosphorus

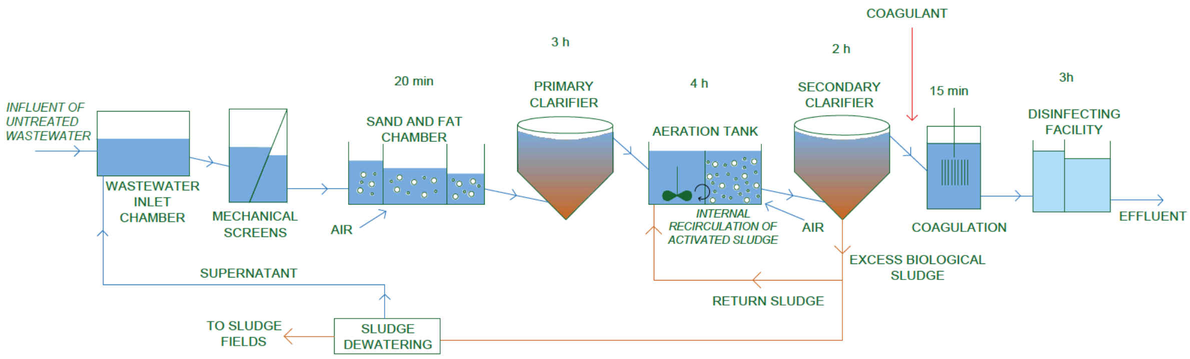


Figure 16. Removal of phosphorus by physicochemical method

The biological reduction of phosphorus concentration in wastewater is based on the fact that some species of anaerobic bacteria are able to accumulate an increased amount of phosphorus in their cells. The physicochemical method is based on the precipitation of phosphorus in the form of low-dispersible compounds, mainly phosphates. Aluminium sulphate – $Al_2(SO4)_3$, iron chloride – $FeCl_3$, calcium hydroxide – $Ca(OH)_2$, etc. may be used for this purpose.

In order to maintain the concentration of sludge needed in aerotank, it shall be continuously returned from the secondary settling vessel to the aerotank in the vicinity of the intake of fresh sewage. The activated sludge to be flowed back into the aerotank constitute 30–60 % of the volume of wastewater.

Wastewater temperature

The temperature of wastewater is a very important parameter, as it affects the chemical and biochemical response rates, impacts the activity of micro-organisms and the solubility of the air in water. If the temperature is below +8 °C, the effectiveness of denitrification of the WWTP is significantly reduced and the quality of the effluent may be reduced. Air and oxygen solubility in water is worsening in summer, and air blowers should be operated more intensively.

Concentration of activated sludge by volume

For the day-to-day operation control of bioreactor, the test of the concentration of activated sludge by volume method shall be used. The wastewater, together with the active sludge, is poured into a measuring vessel of 1 l from the aeration chamber. Measure the volume of precipitated sludge in cm^3/l for 30 minutes or calculate the corresponding percentage. Then dry the gutted sludge for 30 minutes at 105 °C, then weigh. In this way, the concentration of activated sludge measured in g/l is obtained. The concentration of activated sludge depends on the biological wastewater treatment technology and the concentration values of pollutants. In a typical organic WWTP operated on a leaky basis, the concentration of activated sludge is normally between 3 and 4 g/l.

Active sludge index

An active sludge index is determined to ensure that the activated sludge is not swollen and that the oxidation processes in bioreactor are performing qualitatively.

This is determined by the ratio between the concentration of the activated sludge by volume and mass $I_j = V/S$, *ml/g*. For normal activated sludge I_j = 80–100; for light activated sludge 100–180; for sludge bloated, greater than 180 ml/g.

Normal activated sludge is well precipitated, its hydraulic roughness is $U_o > 1$ mm/s, the deposition of light activated sludge is slow, its $U_o < 1$ mm/s, while the bloated activated sludge deposits poorly, its $U_0 < 0.5$ mm/s. The bloat of activated sludge is most commonly caused by the proliferation of filamentary bacteria in the activated sludge and by the addition of gas bubbles to their flakes, a decrease in pH, overloading of activated sludge. The bloated activated sludge soaks very badly. It is more or less floated in a secondary clarifier, but the light, active sludge is partly drained from the discharge. The concentration of activated sludge in bioreactor and circulation sludge, as well as the sludge index, shall be determined at each change. Oxidation processes take place more quickly in the summer at high temperatures, with a lower concentration of activated sludge than in winter.

Activated sludge age

The age of the activated sludge is the average time of the daily presence of the sludge in bioreactor. The age of activated sludge depends on the type of effluent treatment, concentration of activated sludge and recirculation. It typically ranges from 1.5 to 30 days.

Workload of activated sludge

The load rate is the amount of organic matter in wastewater, expressed in BSP$_5$, delivered daily per 1 m^3 bioreactor volume or 1 g of sludge biomass organic dry matter.

Heavily loaded aerotanks ⇨ The load rate is greater than 400 mg/dn. The increase in sludge is small, the level of wastewater cleaning is low, the sludge is poorly removed from wastewater (poorly regulated).

Medium-loaded aerotanks ⇒ The load rate is 150–400 mg/dn per 1 g of the organic dry matter of sludge. In this way, aerotank works optimally, cleaning rates are high, while energy consumption is low.

Low-loaded aerotanks ⇒ The load rate shall not exceed 150 mg BSP[5] per 1 g of the organic dry matter of sludge per day. Aerotanks have a high cleaning capacity but their performance is not sustainable because bacteria periodically experience a lack of food.

Since the load of pollution coming in is almost constant under normal conditions, while the mass of sewage sludge is increasing at all times, the **increase in sludge should be compensated, with the exception of extra activated sludge from the process.** If this is not the case, the weight of the activated sludge in biological wastewater treatment processes is increasing so much that it is no longer possible to separate it from the effluent. Leaching of activated sludge from WWTP starts, entering an environment, which is unacceptable from an environmental point of view. In order to prevent the leaching of activated sludge, in practice all effluent treatment plants provide for a mechanism for removing excess sludge from the purification process.

In order to maintain the activity of sludge separated by secondary guideliners, it is necessary to return the sludge to the aerotank as soon as possible and to remove the excess activated sludge for further treatment and recycling.

If activated sludge is killed

All mechanisms must be maintained in active sludge installations, aerotanks must comply with the concentration of activated sludge required for specific conditions and systematically check the relevant parameters.

Aggravated death of sewage sludge may occur due to the following reasons:

Because of inflowing wastewater ⇒ Very strong salvable pollution (e.g., wastewater from food plants or wastewater brought in from decentralised sewer systems). Increased concentrations of individual pollutants in wastewater (e.g., wastewater from food plants, industrial wastewater, wastewater containing heavy metals). ⇒ Plants that produce high-pollution effluent must install pre-treatment plants.

Cause	Consequence	Remedy
The operation of the WWPS with WWTP has not been coordinated	Thus, during the operation of the pump station, the load of wastewater treatment plants increases significantly and interferes with the WWTP processes.	Harmonising the wastewater supply with the operating regime of pumping plant and WWTP, this can be done by drawing up a schedule for the storage of wastewater.
High volume of rain effluent	Dilutes municipal wastewater and there are not enough nutrients for activated sludge.	Additional nutrients must be provided to sludge.
Outage in the power supply	No air has been delivered to the activated sludge for some time.	Purchase of an electric generator or diesel generator.

If any of these causes persist, the secondary gusher should be cleaned frequently and regularly from the dead sludge!

2.3.2. Quality requirements for wastewater treatment

The composition of wastewater differs significantly from non-polluted waters, which are naturally present as a result of human activity, and it is virtually impossible to clean them up to the quality of unpolluted surface water although they contain significantly less-polluting substances than before purification. This residual pollution also creates what is called a load of effluent **to the environment**. The introduction of untreated wastewater to the open water or to the bottom may cause damage to the environment and human health, and it is, therefore, important to remove the wastewater to the highest possible level of purity.

The MK Regulation No. 34 lays down requirements for the permissible concentration of pollutants in waters issued from sinter urban wastewater treatment plants, in addition to the permit for each of the WWTP polluting activities, the permissible concentration of pollutants permitted to be discharged into the environment is fixed.

2.3.2.1. People equivalent (PE) and its calculation

For the purposes of standardising the load of wastewater discharged to the WTTP resulting from both the drainage of domestic wastewater and the effluent of production, the pollution contained in the wastewater may be described by the theoretical load of one person expressed in terms of people equivalents (PE).

According to MK Regulation No. 34, one PE unit is the amount of organic matter contamination corresponding to the biochemical oxygen consumption of 60 g O_2 per day, which can normally be managed by one adult.

The amount of pollution expressed in PE is calculated on the basis of the annual maximum weekly average quantity of pollution entering the urban WWTP during the year under normal conditions (Equation (1)). In places where there is no industrial production and institutional establishments and they are visited by the same population living in a given area, the PE is generally assumed to be equal to the population, i.e., if the institutional authorities work and are visited by the same population who live in the area, the additional burden of pollution expressed in the PE from the institutional sector should not be taken into account. However, if, for example, there is a school in the area or a nursing home where people living outside the area are also living on a daily basis, one must calculate an additional pollution load expressed in the PE (for each additional person, one CE = PE). An example of the calculation is given in Table 4.

$$CE = \frac{\frac{Q}{N} BSP - 5 \times 10^{3}}{60}, \quad (1)$$

where

N – number of days per year;

Q – total annual wastewater, thousand m^3;

60 – theoretically assumed size (related to the theoretical BSP load produced by one person)

Table 4

Example of PE Calculation

Year	Intake BSP_5, mg/l	Total annual wastewater, m^3	CE
2012	149.8	8 939 555	60 987
2013	180.0	7 769 491	63 878
2014	193.7	7 223 589	63 900
2015	237.9	6 689 963	72 688
2016	225.7	6 045 187	62 151
2017	195.7	6 308 43	56 387
2018	242.0	5 439 239	60 124
2019	269.3	5 246 112	64 512
2020	231.8	5 380 815	56 811

In the case of **industrial production** in the area, the PE (equal to the population) must be accompanied by commercial and industrial pollution expressed in PE.

In such cases the following calculation shall be used:

$PE_{total} = PE_{population} + (BSP_5$ pollution concentration (mg/l) × daily wastewater volume $(m^3/dn)/1000)/60$

The pressure exerted by heavy rain and other atypical conditions shall not be taken into account in these calculations. For planning purposes, the amount of pollution expressed in PE may be calculated on the basis of the number of inhabitants and establishments to which the connection is intended and depending on the values of water consumption and biochemical oxygen consumption of wastewater (BSP_5).

2.3.2.2. Monitoring of the quality of wastewater

The quality of wastewater may be variable in annual, seasonal, monthly, daily and hourly terms, and therefore it is necessary to carry out regular monitoring of the quality of wastewater. Depending on the size of the treatment plant, it is recommended to perform it from several times a day, possibly by monitoring the quality of the wastewater with online sensors and systems, up to once a year.

The monitoring of the quality of wastewater shall be regular laboratory tests for discharges and effluent at the WWTP, which shall be performed for the determination of performance of the WWTP.

The frequency and parameters of the monitoring of wastewater quality shall be determined both by the conditions laid down in the VVD authorisation and by the internal systems for monitoring the quality and performance of WWTP developed by operators themselves. Within the framework of the internal monitoring system, a laboratory examination of wastewater may be carried out by its own forces and by the personnel of appropriate qualifications, but it is necessary to carry out investigations in accredited laboratories within the framework of the VVD reporting system.

VVD authorisation

In order to carry out appropriate wastewater treatment, the VVD's authorisation for the performance of polluting activities should be obtained. The permit issued by the VVD for a polluting activity of categories A, B or C shall include requirements for the monitoring performed by the operator of WWTP and determine the frequency of monitoring, taking into account the requirements specified in MK Regulation No. 34, regulatory enactments regarding the monitoring of surface water, groundwater and protected areas, and regulatory enactments regarding environmental monitoring and the register of polluting substances, as well as the nature of emissions, type, and quality requirements for accepting waters. The VVD shall develop and approve for each effluent discharge the conditions for the discharge of wastewater, which shall be specified in the permit.

Responsibility for monitoring

The operator of WWTP shall be responsible for the fulfilment of the monitoring requirements, which shall ensure the quality control of wastewater in an accredited laboratory. Monitoring of the quality of wastewater should be carried out on both incoming and effluent. All analytical results shall be entered in the wastewater quality register.

Reports

An accredited laboratory shall issue a test report regarding the analyses performed, which shall continue to be used for preparing quarterly reports on the calculation of taxes on natural resources in accordance with the Law of 15 December 2005, "Law on Natural Resources Tax", and Cabinet Regulations No. 404 of 19 June 2007, "Procedures for the Calculation and Payment of Natural Resources Taxes and for Issuing Permission to Use Natural Resources".

Causes of quality non-compliance with the requirements of regulatory enactments

If the quality of the WWTP effluent discharged does not comply with the requirements of the regulatory enactments (the justification of the problem is the analysis of the wastewater), it must first be understood how justified is the identified problem and what the causes are.

Short-term problem ➡	Related, for example, to the operation of a system-using manufacturing plant, which, due to an accident, has led to a large volume or high concentration of wastewater in a centralised wastewater system pre-treatment plant. After the elimination of an accident, the wastewater analyses should comply with the requirements of regulatory enactments.
Regular problem ➡	Related, for example, to the operation of a system-using establishment, which has discharged a large volume or high concentration of wastewater in the centralised sewage system. In such a case, negotiations should be conducted with the industrial company on the functioning of their treatment facilities, and penalties should be imposed for the discharge of increased pollution into WWTP.
Long-term problem ➡	It is likely that equipment or individual components do not function. A reinforced survey of equipment and a technical state test is required. Repair, reconstruction or replacement of equipment should be carried out accordingly.

3. SEWAGE SLUDGE

In this handbook, in the technical literature of wastewater technology and in the context of the Latvian wastewater sludge management strategy, **sewage sludge refers to sludge that occurs directly in municipal WWTP**, which provides adequate public service for the collection and treatment of wastewater, and therefore the handbook does not include information related to materials generated by the production wastewater treatment process, for example, flotation foams or sludge, their peculiarities and management requirements and practices.

In municipal wastewater treatment plants, gross mechanical impurities, as well as sand and primary sludge from primary leeches, are classified as waste, not as sewage sludge, and do not come into wastewater sludge treatment lines or sludge fields.

In mechanical and chemical WWTPs, sewage sludge is not formed in the classical sense. The solid fraction accumulated in mechanical WWTPs is municipal waste and is disposed of in landfill sites. Pysical-chemical WWTPs accumulate the so-called flotation sludge, which, by nature and composition is a different mass compared to conventional sewage sludge. The disposal of such sludge is not described and is not possible according to the types of wastewater sludge disposal provided for in MK Regulation No. 362. However, the solid mass of wastewater is added to the sewage sludge, which precipitates in the primary guideliners of WWTPs. Although it is not sewage sludge in the classical sense, the treatment of this mass may be organised together with the treatment of sewage sludge. This type of sediment in primary guideliners is only formed in the Riga WWTP (BAS "Daugavgrīva"), where a technological solution for wastewater treatment is used from all other wastewater treatment plants of Latvia.

This chapter uses widely available information and data from the training course material developed by J. Jansons and others "Waste Water Treatment Plant Operators and Environmental Specialists Training Course", 2006, Riga.

3.1. Types and characteristics of sludge

In order to ensure a common understanding and access to the management of sewage sludge depending on **the moisture content, it shall be divided into the following groups**:

Wet sludge	⇒	Sludge removed from the biological wastewater treatment process. It contains approximately 1 % (10 kg/m ^{3}) of sludge dry matter and 99 % (990 kg/m ^{3}) of water.
Wet sludge	⇒	Sludge dehydrated using one of the dewatering plants (centrifuges, filtering presses, screws and other technologies). Wet sludge may contain a different dry matter content, but on average it is approximately 15–16 % (150–160 kg/m^3).
Sludge dry matter	⇒	The dry matter of the sludge is called the dry residue, which remains over after all the water has been evaporated from the sludge. The dry matter of sludge is a convenient parameter in various calculations, since it allows for an assessment of the amount of sewage sludge produced in WWTP, regardless of how much water is produced in the wastewater sludge.

Depending on the wastewater treatment technology used and according to the effluent sludge generated, it shall be defined according to the technological process of purification in which it arises:

- primary sludge;
- secondary sludge;
- excess sludge.

The sludge generated by different technological processes differs in terms of physical, chemical and biological properties, so different solutions may be needed for the treatment and processing of sludge.

Characteristics of municipal sewage sludge by humidity

Sewage sludge →

- humidity 82–86 % → similar to liquid mud
- humidity 86–90 % → similar to the consistency of cream
- humidity >90 % → forms a liquid running mass

Primary sludge →

Obtained in a primary guideliner, its size depends on the time of passage and the volume of the tank. Primary sludge contains a large number of organic compounds and is optimally suitable for anaerobic treatment. The primary sludge is very heterogeneous, forming a reckled, grey or grey-brown suspension with a sour smell. Given that the primary sludge contains a lot of organic matter, it blows quickly, getting dark gray or black and releasing an unpleasant sour smell. The average humidity of sludge separated from primary leeches is approximately 95 % if the sludge is separated by self-flow, and approximately 92 % if the reciprocating pumps are used. The average organic fraction content is 67 %. In the sludge of primary leeches, the protein is approximately twice less, while there are 2.5 to 3 times more hydrocarbons are than in the activated sludge. This kind of

Secondary sludge	⇒	Obtained **as a result of the biological treatment** of wastewater, which normally follows primary purification. The classical biological wastewater treatment process (aerotank) has high concentrations of bacteria and micro-organisms. The period of residence of bacteria and micro-organisms in aerotank is between 10 and 12 days, depending on the temperature of air and wastewater, the amount of wastewater pollution coming into WWTP and the method of removing nitrogen. In order to remove nitrogen, bacteria need a lifetime when they grow and therefore require sludge circulation (**active sludge recirculation**). Secondary biological sludge is no longer needed (extra sludge).
Superfluous sludge	⇒	Sludge **removed from the biological process** is a suspension containing amorphous flakes and encircling aerobic bacteria and the simplest micro-organisms with low and adsorbed sewage contamination. When storing and contracting excess sludge, it begins to rot quickly. Excluding sludge from secondary leeches after aeration tanks, their humidity is approximately 99.0–99.5 %, but after biofilters 96–96.5 %. The humidity of the excess sludge is approximately 98 % after exposure to the vertical thickeners, while the humidity of the activated sludge is approximately 97 % after welling in the radial thickeners. Organic matter content depends on the amount of precipitation used and is on average 70 % to 80 %. The bacterial content is much higher, given that it has grown in the process of biological purification. Most commonly, excess biological sludge is much worse than the primary sludge.

3.2. Activated sludge

The activated sludge used in the biological treatment of wastewater is a complex “society” or cenosis of microscopic organisms, adapted in the course of development to the specific wastewater pollution spectrum and to the special features of the operating regime of treatment plants. It consists mainly of bacteria and single cells (Figure 17).

Figure 17. Part of the activated sludge in the microscope

The number of bacteria in the activated sludge ranges from 108 to 1014 cells per 1 g of dry matter.

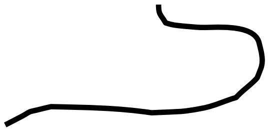
A small part of the bacterial activated sludge is free or merged into stranded colonies. However, the majority (90–95 % of the total mass of bacteria) consists of flakes or flocules, which also determines the physical structure of the sludge as a whole. The colour of flocules is usually dark brown (may also be grey or yellowish), but the size ranges from 0.1– 0.5 to 2– 4 mm. They also contain inorganic solid particles. Mucus released by bacterial cells, consisting mainly of polysaccharides, serves as a binding agent. Additional slime function is the protection of bacteria from the adverse effects of sewage pollution. The capacity to produce polysaccharides and thus contribute to the formation of flocules is present in the bacteria of the genus *Zoogloeia, Pseudomonas, Aeromonas, Acinetobacter, Micrococcus, Paracoccus*.

The formation of flocules is one of the most important properties of activated sludge (Figure 18). This makes possible the sedimentation of activated sludge in a secondary guideliner, which ensures the separation of sludge from the effluent in the aerotank. The active sludge has a relatively large surface of up to 100 m^2 per 1 g of dry matter. During the first stage of biological treatment of wastewater, mechanical removal of pollutants from water takes place in the first 30 minutes after mixing with the activated sludge due to adsorption on the sludge surface. This is followed by a biochemical oxidation process of adsorbed contamination.

Freely floating sludge. Small particles of sludge that have not yet merged into larger flakes.

Loose-floating sludge particles have rallied into larger flakes, but they are still amorphous and unstable.

Filamentary bacteria. Can “freeze” sludge flakes, providing them with good mechanical resilience.
They must be in a certain proportion to the other sludge components. Excessive proliferation of threaded bacteria can cause problems.



Perfect flake of activated sludge. Contains bacteria, amoebas, filament bacteria, biopolymers released by bacteria.

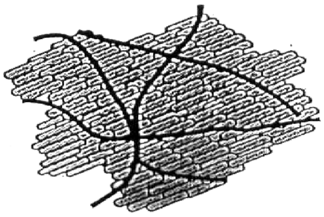


Figure 18. Formation of activated sludge flakes

3.2.1. Chemical composition of activated sludge

The chemical composition of the active sludge depends heavily on the regulatory parameters of the effluent composition, sewage treatment technology and WWTP (Table 5).

Table 5

Chemical Composition of Active Sludge in Latvia[5]

Substances	Dry matter (%)	Dry matter (g/kg)
Volatile organic matter	50–88	
Protein (protein)	32–41	
Nitrogen	2.4–5	24–50 [N]
Phosphorus (expressed as P_{205})	2.8–11	12–48 [P_{cop}]
Potassium (expressed as K_{2O})	0.5–0.7	

Effective and stable activity of activated sludge can be achieved by creating conditions favourable to bacteria and other micro-organisms, by continuously providing them with food and oxygen, and by preventing the introduction of harmful substances into aerotank. The most dangerous for bacteria are heavy metal salts and oxidising agents such as chlorine, ozone, silver and copper compounds. The poisonous activated sludge has phenols, alcohols, formalin,

[5] Study on wastewater sludge treatment technologies used in Latvia (2021), LUKE

formaldehyde, etc. Dissolved oxygen deficiency has a significant effect on the functioning of aerobic bacteria and other micro-organisms.

If oxygen is not supplied to the aerotank, bacteria die after 2 to 4 hours!

3.2.2. Physical properties of activated sludge

In WWTP, activated sludge can be assessed operationally using a simple method based on the determination of the physical properties of sludge. The weight of the activated sludge shall be dived into the glass container and determined visually: the size of the sludge flakes, their settling rate, colour (yellowish, brownish, brown-green, grey, black), the permeability of the water over the gulated layer of sludge (transparent, cloudy), the smell (swamp, rotting), the position of the sludge (dense, normal, bloated) and the temperature.

3.2.3. Theoretical calculation of the increase in activated sludge

The actual amount of excess activated sludge, i.e., the increase in sludge, depends on many conditions: loads of incoming pollution, nutrient balances in wastewater, sewage temperature, sludge age and other factors.

Nevertheless, the approximate increase in activated sludge in wastewater treatment plants can be calculated in theory (see the example in Table 6) using an empirical formula (2) normally used to determine the yield of wastewater sludge dewatering plants:

$$P = 0,5\frac{[\mathrm{SV}]}{[\mathrm{BSP}_5]} \times Q \times \frac{[\mathrm{BSP}_5]}{1000} \qquad (2)$$

where

P − increase in sludge, kg/d;

[SV] − suspended matter content in wastewater, mg/l;

[BSP_5] − biochemical oxygen consumption in wastewater, mg/l;

Q − effluent flow rate, m^3/d.

Table 6

Example of an Increase in Activated Sludge

[SV] – detainment of suspended substances in wastewater	285	mg/l
[BSP_5] – biochemical oxygen consumption in wastewater	232	mg/l
Q – wastewater flow rate	14 742	m^3/d

$$P = 0,5\frac{[285]}{[231]} \times 14742 \times \frac{[231]}{1000} = 2101 \text{ kg/d theoretical increase of sludge}$$

3.2.4. Concentration and measurement of activated sludge

In order to ensure the most efficient treatment of wastewater, one of the main tasks of the operator of wastewater treatment plants is to maintain a constant and appropriate concentration of activated sludge in bioreactors. Accordingly, a uniform and consistent methodology should be used to measure the concentration of activated sludge in bioreactors, including the actual amount and increase of excess activated sludge to be pumped from bioreactors. There are two main methods for measuring the amount of sludge.

Volumetric method (determination of the volume of sludge)

The method is very simple and requires minimal equipment. Pour approximately 1 litre of activated sludge from the bioreactor into a measuring cylinder (or another suitable container). The sludge will begin to precipitate and a clear layer of water will form on the surface of the measuring cylinder. After 30 minutes, the operator of the WWTP must measure the volume of activated sludge used to assess the amount of activated sludge. A capacity of up to 500–700 ml/l is assumed to be optimal and means that the removal of activated sludge is not yet necessary. If the volume of the activated sludge is greater, the excess activated sludge must be removed.

The method is considered to be very inaccurate, as the characteristics of sludge sedimentation may vary in a wide range. If the sludge is "heavy" and is well precipitated, 500 ml/l may be a very large amount of sludge, whereas in cases where the sludge is swollen and light, 700 ml/l may correspond to a relatively small amount of sludge. For such nuances to be correctly assessed, an experienced operator is required.

The referred method is widely used in the small WWTPs of Latvia, where the involvement of the laboratory and external laboratory for the monitoring of the amount of sludge is considered to be economically unjustified.

Filter/drying method

A certain amount of sludge is passed from the bioreactor and filtered with a special filter that does not change the weight when heated. The amount of sludge to be filtered is normally between 25 ml and 100 ml, depending on the concentration of the sludge. Sludge remaining on the filter is dried at 50 ºC to constant weight (that is, until drying does not materially change the weight of dried sludge remaining on the filter). By knowing the volume of filtered sludge and the mass of sludge after drying, the dry-matter concentration of the sludge in the sample, normally expressed in g/l, may be calculated. The method allows for an overall accurate assessment of the amount of sludge in the system. This method is proposed by all accredited laboratories involved in wastewater analysis and also in major urban WWTPs.

In order to accelerate the extraction of the results of sludge concentration measurements in the biological wastewater treatment process, stationary and mobile metering devices are also available, which, when calibrated in the laboratory, can obtain a level of sludge concentration in g/l. These types of devices require a greater contribution of resources, but the practice shows that they justify the costs by allowing to produce rapid data at any point in the biological wastewater treatment process.

3.2.5. Sludge composition

Depending on the type of wastewater treatment and the process of removing sewage sludge, sewage sludge may be divided into five different types according to physical, chemical and biological characteristics (see Table 7):

- primary sludge from the mechanical or chemical treatment process, sludge with high concentration of pollutants;
- activated sludge (medium-polluted wastewater);
- activated sludge (contaminated wastewater);
- mixed sludge;
- stabilised sludge.

Table 7

Sludge Composition Depending on the Processing[6]

Parameter	Primary sludge	Activated sludge (medium-polluted wastewater)	Activated sludge (contaminated wastewater)	Mixed sludge	Stabilised sludge
Dry matter, g/l	12	9	7	10	30
Organic matter, % dry matter	65	67	77	72	50
pH	6	7	7	6,5	7
Parameter	**Primary sludge**	**Activated sludge (medium-polluted wastewater)**	**Activated sludge (contaminated wastewater)**	**Mixed sludge**	**Stabilised sludge**
C, % in organic matter	51.5	52.5	53	51	49
H, % in organic matter	7	6	6.7	7.4	7.7
O, % in organic matter	35,5	33	33	33	35
N, % in organic matter	4.5	7.5	6.3	7.1	6.2
S, % in organic matter	1.5	1	1	1.5	2.1
C/N	11.4	7	8.7	7.2	7.9
P, % in dry matter	2	2	2	2	2
CL, % in dry matter	0.8	0.8	0.8	0.8	0.8
K, % in dry matter	0.3	0.3	0.3	0.3	0.3
Al, % in dry matter	0.2	0.2	0.2	0.2	0.2

[6] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of wastewater treatment plants and environmental specialists", 2006, Riga

Parameter	Primary sludge	Activated sludge (medium-polluted wastewater)	Activated sludge (contaminated wastewater)	Mixed sludge	Stabilised sludge
Ca, % in dry matter	10	10	10	10	10
PV, % in dry matter	2	2	2	2	2
Mg, % in dry matter	0.6	0.6	0.6	0.6	0.6
Fat, % in dry matter	18	8	10	14	10
Protein, % in dry matter	24	36	34	30	18
Carbohydrates, % in dry matter	16	7	10	13	10
Calorific value, kWh/t in dry matter	4200	4100	4800	4600	3000

The amount of pollutants in sludge depends mainly on the composition of the wastewater to be processed, so the exclusion of harmful substances from production processes and the pretreatment of industrial wastewater is important for improving the quality of sludge.

Organic matter in sludge

Organic substances in sludge consist mainly of soluble compounds (hydrocarbons, amino acids, low-molecular protein and lipids). On average, the organic matter shall be at least 50 % of the dry matter, which may be reduced by sludge treatment. The organic matter content of sludge and other organic fertilisers depending on the type of treatment is shown in Table 8.

Table 8

Organic Matter in Sludge, Depending on the Type of Processing[7]

Type of sludge treatment	Organic matter, % of dry matter
Aerobic fermentation	60–70
Anaerobic fermentation	40–50
Drying	<40
Sludge compost	50–85
Municipal waste compost	40–60
Garden residues compost	30–60
Manure	45–85

[7] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris “Training course for operators of wastewater treatment plants and environmental specialists”, 2006, Riga

Nitrogen and phosphorus in sludge

In EU countries, the wastewater sludge dry matter contains on average between 20 and 80 g/kg of nitrogen (N) and 10 to 90 g/kg of phosphorus (P). According to the amount of nitrogen, sludge is comparable to manure, but there is even more phosphorus (Table 9).

Table 9

Nitrogen and Phosphorus Content in Sewage Sludge[8]

Material	Total nitrogen (N), % in dry matter	N-NH_4, % of total N	Phosphorus (P), % in dry matter
Liquid sludge	1–7	2–70	0.9–5.2
Dehydrated sludge	2–5	<10	
Dry sludge	1–3.5	<10	
Composted sludge	1.5–3	10–20	0.2–1.5
Municipal waste compost	0.96	-	0.39
Garden residues compost	1.0–2.4	-	0.04–0.44
Litter	2.2–4.4	10	0.61–1.61
Manure	4–7	50–70	0.91–3.3

Nitrogen in sludge is mainly in the form of organic compounds and in small concentrations in the form of ammonium compounds. Most of the ammonium salts are in the liquid fraction of the sludge and are separated by dewatering the sludge. The nitrogen content of sludge is also reduced during storage as a result of denitrification processes. Effects of different treatment techniques on the nitrogen content of sludge are shown in Table 10.

[8] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of wastewater treatment plants and environmental specialists", 2006, Riga

Table 10

Nitrogen Content Change Depending on the Type of Treatment[9]

Type of processing	Total nitrogen (N), % in dry matter	$N\text{-}NH_4$, % of total N
Liquid sludge		
Aerobic fermentation, sedimentation	5–7	5–10
Aerobic fermentation, mechanical sedimentation	4–7	2–8
Anaerobic fermentation	1–7	20–70
Partially dehydrated sludge		
Aerobic fermentation, sedimentation	3–5.5	<5
Aerobic fermentation, mechanical sedimentation	1.5–3	<5
Dehydrated sludge		
Aerobic fermentation, kayaking and dewatering with filtrator	2.5	<10
Composting	1.5–3	10–20
Aerobic fermentation, dewatering in sludge filtration	2–3.5	<10
Anaerobic fermentation, dewatering in sludge fields	1.5–2.5	<10
Dried sludge	3.5–6	10–15

Phosphorus in sludge is mainly in mineral form (30–98 % of total phosphorus). The amount of phosphorus available for plants depends on the sludge treatment method and not on the total phosphorus content (Table 11). The largest total phosphorus content is in sludge resulting from chemical or biological phosphorus precipitation. The phosphorus content does not change significantly during storage.

Table 11

Phosphorus in Sludge[10]

Type of processing	Phosphorus (P_{2O5}), % in dry matter	Phosphorus (P), % in dry matter
Liquid sludge, anaerobic treatment	4.9–6.9	2.1–3
Aerobic fermentation	2.5–12.7	1.1–5.5
Primary sludge, kayaking	2.5–12	1.1–5.2

Other nutrients in sludge

Wastewater sludge contains a small amount of potassium, calcium, sulphur, magnesium, sodium and various trace elements. The potassium content of sludge is relatively small – 0.2–

[9] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of waste water treatment plants and environmental specialists", 2006, Riga

[10] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of wastewater treatment plants and environmental specialists", 2006, Riga

0.4 %, and therefore, when sludge is used as a fertiliser, the mineral potassium additive is most commonly needed. When sulphur content is 1.5–2 %, sludge can serve as a very efficient sulphur fertiliser, such as peat soils.

Heavy metals in sludge

One group of toxic substances in sludge is heavy metals. Metals of a density exceeding or close to iron density of 7.87 g/cm^3 are normally added to this group of substances.

Maximum levels of heavy metals in sewage sludge are set by EU Directive 86/278/EEC. The average concentration of heavy metals in all EU countries is below the maximum level (see Table 12). Concentrations of heavy metals are exceeded mainly in industrial sludge, as well as in urban rain wastewater.

Table 12

Concentration of Heavy Metals in Sewage Sludge[11]

Metal	Limiting concentrations as defined in	Average in Latvia
Cadmium (Cd)	20–40	0.4–3.8
Chromium (Cr)	1000–1750	16–275
Copper (Cu)	1000–1750	39–641
Mercury (Hg)	16–25	0.3–3
Nickel (Ni)	300–400	9–90
Lead (Pb)	750–1200	13–221
Zinc (Zn)	2500–4000	142–2000

3.2.6. Sludge quality requirements

Wastewater sludge is essentially a surplus of activated sludge, which is removed from the secondary gusher after sedimentation. Consequently, the composition of sewage sludge is determined to the greatest extent by the original composition of the activated sludge.

The quality of sewage sludge can be determined by three different sets of indicators:

Agrochemical indicators ⇨ Dry matter content, pH response after KCl, organic matter in dry matter, total nitrogen in dry matter, total phosphorus content in dry matter

Microbiological pathogens ⇨ Bacteria, viruses, parasitic single-cells and parasitic maggots

[11] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of wastewater treatment plants and environmental specialists", 2006, Riga

Indicators for heavy metals and organic pollutants	➡	Cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn)

According to MK Regulation No. 362, the quality of sewage sludge is expressed and regulated only by indicators of heavy metals and their concentrations in sewage sludge.

Five quality classes of sewage sludge are distinguished, the first of which is the highest but the fifth – the lowest (see Table 13). The sludge quality classes are not distinguished by agrochemical, pathogenic or organic pollutants; individual agrotechnical indicators (soil pH) are taken into account when deciding on the use of sludge and its amount in agricultural land.

Table 13

Classification of Sewage Sludge and its Compost into Classes

No.	Class *	Mass concentration of heavy metals in dry matter (mg/kg)						
		CD	CR	Cu	Hg	Ni	WB	Zn
1.	I	<2.0	<100	<400	<3.0	<50	<150	<800
2.	II	2.1–5.0	101–250	401–500	3.1–5.0	51–100	151–250	801–1500
3.	III	5.1–7.0	251–400	501–600	5.1–7.0	101–150	251–350	1501–2200
4.	IV	7.1–10	401–600	601–800	7.1–10	151–200	351–500	2201–2500
5.	V	>10	>600	>800	>10	>200	>500	>2500

* If the relevant value of the higher-class sludge is not more than 30 % higher than the mass concentration of only one heavy metal, this sewage sludge and its compost shall be into the higher class.

Treated sewage sludge of Class 1 and 2 may be used in agriculture, the use of Class III and Class IV sludge in agriculture is limited. Class 5 sewage sludge is considered to be hazardous waste. All activities with Class 5 sewage sludge shall be carried out in accordance with the regulatory enactments regarding waste management.

According to the requirements of MK Regulation No. 362, the quality of sewage sludge shall be determined for each series of sewage sludge (mass of sewage sludge with a uniform chemical composition, similar physical and other characteristics), producing one average sample.

Table 14

Average Sample of Sewage Sludge in Treatment Plants

No.	Load of waste water treatment plants (human equivalent)	Average number of samples per year	Average sampling period (months)	Periodicity of individual sampling	Number of samples to be tested per year		
					For the detection of heavy metals *	For determination of agrochemi-cal indicators	For determination of the dry matter content * *
1	<2000	1	12	2 times a month	1 * * *	1	2
2	2001–5000	1	12	2 times a month	1 * * *	1	4
3	5001–10000	2	6	3 times per month	2	1	6
4	10001–50000	3	4	Once a week	3	2	12
5	50001–100000	4	3	every three days	4	3	24
6	>100000	12	1	every day	12	4	52

* If during the last two years in all wastewater sludge series, the concentration of certain heavy metals has not exceeded the values corresponding to the first class, testing for the determination of these metals may be carried out twice, but not less than once a year.

* * The dry matter content shall be determined in individual samples immediately after their collection.

* * * If only municipal wastewater is treated in a treatment plant, the mass concentration of heavy metals should not be determined.

According to the requirements of MK Regulation No. 362, the testing methods to be used for the determination of agrochemical indicators and heavy metals are summarised in Tables 15 and 16. The testing methods vary from sector to sector, and it is therefore essential to focus on the methods used to perform the measurements in question.

Table 15

Quality Indicators and Test Methods to be Determined for the Average Sample of Wastewater Sludge and its Compost Series

No.	Heavy metals	Methods *	
		for the preparation of samples	for testing
1	Cadmium (Cd)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
2	Chromium (Cr)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
3	Copper (Cu)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
4	Mercury (Hg)	LVS 346: 2005	LVS 346: 2005
5	Nickel (Ni)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
6	Lead (Pb)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
7	Zinc (Zn)	LVS ISO 11466: 1995	LVS ISO 11047: 2003

* Other methods of atomic absorption spectrophotometry with limit values not exceeding 1 mg/kg – Cd; 12 mg/kg – Cr; 5 mg/kg – Cu; 12 mg/kg – Ni; 15 mg/kg – Pb; 0.2 mg/kg – Hg; and 10 mg/kg – Zn may also be used.

Table 16

No.	Agrochemical indicators	Test methods
1	Environmental reaction (pH_{KCl})	LVS ISO 10390: 2002
2	Amount of organic matter (%)	LVS ISO 10694: 1995
3	Nitrogen (N) in dry matter (g/kg)	LVS ISO 11261: 2002
4	Ammonia nitrogen ($N\text{-}NH_4$) in dry matter (g/kg) by extraction of KCl	ISO/TS 14256-1:20 03 ISO 14256-2:20 05 (E)
5	Phosphorus (P) in dry matter (g/kg)	LVS 398: 2002 EN 14672: 2005
6	Dry matter (%)	LVS ISO 11465: 1993 LVS EN 12880

According to the requirements of MK Regulation No. 34, the producer of sewage sludge shall draw up an appropriate quality certificate for each series of sewage sludge on the basis of the resulting sewage sludge quality indicators. The quality certificate must indicate both the agrochemical characteristics of the sludge or its compost series and the content of heavy metals.

The producer of sewage sludge and compost shall issue a copy of the quality certificate to the user of sewage sludge and compost – to a legal or natural person engaged in the storage, use and disposal of sewage sludge and compost. The producer of sewage sludge and compost shall register the quality certificate for each series in a special registration journal. In the quality certificate column “Class” one should write “municipal sewage sludge” or “compost of municipal sewage sludge”.

Wastewater sludge and compost quality testing reports and original quality certificates, as well as registration journals, shall be kept for a period of not less than ten years.

4. WASTEWATER SLUDGE MANAGEMENT

In line with international experience and available technologies in the field of wastewater sludge management, a variety of activities are possible in order to ensure full management. (Figure 19).

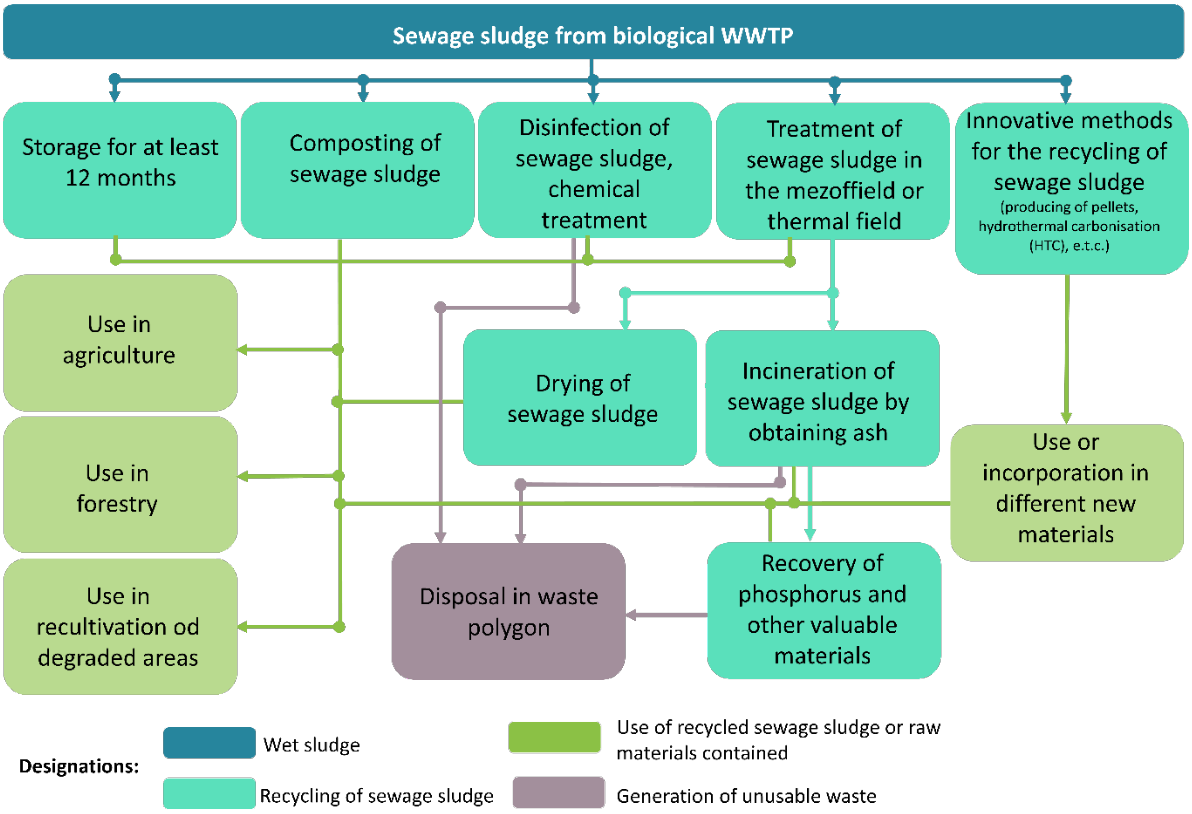


Figure 19. Most widely used solutions for wastewater sludge management[12]

In order to avoid potential risks of environmental pollution and to ensure compliance with the basic principles of the circular economy, all sewage sludge that arises in the WWTP must be properly treated, recycled and disposed of or managed, so that wastewater and sludge management is an integral part of domestic activity of the WWTP. It is essential not to lose the nutrients contained in sewage sludge in order to use the processing product and to handle the sludge in an efficient and sustainable way. Sewage sludge must be recycled in such a way that the feed materials are not removed back to the water tanks, but waste water sludge material and energy resources can be used.

[12]Waste water sludge management strategy in Latvia, LWWWWA, 2021

MK Regulation No. 362 defines the permitted treatment of sewage sludge. The wastewater sludge processing technologies used in Latvia are described in detail in "Study on wastewater sludge processing technologies used in Latvia" (Association of Latvian Water Supplies and Sewers, project *LIFE GOODWATER IP*, 2020)[13], "Survey on the quality of municipal sewage sludge in Latvian water plants, development of proposals for processing and use (Latvian Biotechnology Association, 2015).[14]

4.1. Aims and requirements of management

The treatment of sewage sludge is a process which makes sewage sludge compliant with certain environmental standards or other quality standards specified for the use of sewage sludge.

The main tasks of the treatment of sewage sludge:

1) to reduce the volume and mass of sewage sludge, mainly by reducing its moisture;
2) to reduce the unpleasant smell;
3) to improve hygienic properties by reducing the amount of pathogenic micro-organisms;
4) to improve physical properties: minimize colloidal structure, reduce volume, etc.;
5) partially reduce the concentration of individual persistent organic pollutants.

According to MK Regulation No. 362, sewage sludge may be considered treated if it has undergone at least one of the following treatments (It is recommended that the terminology used be reviewed during the development of the Strategy, the recommended explanations can be found in the "Terminology" section):

1) storage, including in liquid form, for at least 12 months (cold fermentation) without mixing and displacement during the storage period;
2) anaerobic decomposition 35 ± 5 °C, minimum treatment time – 21 ± 5 days;
3) thermophilic anaerobic decomposition 55 ± 5 °C, minimum treatment time – 10 days; aerobic stabilising of thermophiles 55 ± 5 °C, minimum treatment time – 10 days;
4) composting during which at least for three days the temperature inside the pile must be not less than 60 °C, 50 cm from the surface of the pile;
5) lime treatment up to pH = 12 or more (not less than two hours after which the temperature must be at least 55 °C);
6) pasteurisation for at least 30 minutes at 70 °C;
7) drying at approximately 100 °C until the dry matter content in the mass of sewage sludge reaches at least 70 %.

Wastewater sludge which has been subjected to biological, chemical or thermal treatment, long-term storage or any other suitable process shall be considered to have been treated according to European Union Directive 86/278/EEC in order to significantly reduce the fermentability of sewage sludge and the health risks arising from their use.

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[13] www.goodwater.lv

[14] https://lvafa.vraa.gov.lv/faili/materiali/petijumi/2014/Apsekojums%20LVAF%20Cleantech%20Latvia%202014.pdf

4.2. Conditions for the selection of the method for the treatment and processing of sewage sludge

In view of the variable composition of wastewater, an individual approach should be established for the dewatering and recycling of sewage sludge. The choice of the technological scheme and method for the treatment of sewage sludge must be based on technical and economic grounds, taking into account local conditions, the characteristics of sewage sludge, the provision of reagents, the existence of technological transport and the possibilities for the disposal of treated sewage sludge.

The main physical chemical parameters by which the choice of the technological scheme, the choice of equipment, its parameters and the working conditions is made are:

1) capacity for the return of sewage sludge water, specific resistance;
2) the specific filtering capacity;
3) compressibility during dewatering (forms of water and solid-phase particles);
4) chemical composition.

The investigation of certain characteristics of sewage sludge is carried out taking into account changes in the characteristics of the active sewage sludge during the preparation process prior to dewatering. Capital and operational costs depend on local conditions and indicators such as electricity rates, reagents, quantities and doses of reagents, dewatering rates of sewage sludge, etc.

Capacity of the return of sewage sludge water

The majority of moisture in sewage sludge is in a related way and therefore has a poor capacity to return water. As indicated above, the organic portion of sewage sludge is quickly blown away by releasing an unpleasant smell while at the same time increasing the amount of colloidal and small dispersion particles, which contributes to a further reduction in the capacity of the return of sewage sludge water. The rate of return of sewage sludge water depends to a large extent on the size of its solid-phase particles. It has been scientifically proven that the higher the particulate matter of the solid phase of sewage sludge, the higher the capacity to return sewage sludge water. The dispersion phase of sewage sludge contains organic and mineral particles of different dimensions, shapes and properties.

The chemical composition of[15] sewage sludge has a significant impact on the reduction of the capacity to return water. Compounds of iron, aluminium and bromine, as well as acids, alkali and other substances present in effluent, contribute to a more intensive return on sewage sludge water and allow for a reduction in the use of chemical reagents for coagulation or flouring of sewage sludge prior to dewatering. In contrast, oils, fats, nitrogen compounds and filamentary substances are undesirable substances in the treatment of sewage sludge. By committing particles of sewage sludge, they worsen coagulation processes and increase the organic matter content of sewage sludge, which significantly erodes their capacity to return water.

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[15] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of wastewater treatment plants and environmental specialists", 2006, Riga

Specific filtration capacity of sewage sludge

Specific filtration resistance of the effluent sludge – resistance of the solid-phase mass unit formed on the filter area unit during suspension filtration at a constant suspension pressure where the viscosity of the liquid phase is equal to 1.0.

The return of sewage sludge water depends on its granulometric composition and solid phase. It has also been demonstrated that increasing of the size of the solid-phase particles reduces the specific resistance of sewage sludge. On the other hand, the specific resistance of sewage sludge is increasing when it is removed from sewage sludge particles of large fractions of the solid phase.

When dehydrating pretreated sewage sludge (after coagulation or floculation), filtering is significantly faster, but the filtering process will slow down just as quickly when reaching a solid-phase concentration of 18–35 %. On the basis that dehydrated sewage sludge is assimilated to the category of compressed materials which deform at higher pressure, the specific resistance of sewage sludge is also increased by increased pressure. In order to use specific resistance to a parameter describing the capacity to return sewage sludge water, the comparison of the specific resistance of different types of sewage sludge can only be carried out by measurement at the same constant pressure.

It is recommended that the measurement of the specific resistance of sewage sludge be carried out at a pressure of 0.067 MPa (500 mm Hg h.).

In municipal wastewater treatment plants, primary gusher sludge and non-harmed activated sewage sludge have significantly less specific resistance than fermented sewage sludge. The specific resistance of fermented sewage sludge depends not only on its type and method of cleaning, but also on the timing of removing and mixing in methane extraction tanks. The long-term retention of sewage sludge in methane extraction tanks may result in a reduction in their specific resistance.

The specific resistance of activated sewage sludge may vary from 75 x 1010 to 1860 x 1010 cm/g. Despite the specific composition of the active sewage sludge, its specific resistance is significantly affected by the initial concentration. The specific resistance is rapidly increasing with the active concentration of sewage sludge.

The aim of concentrating the active sewage sludge in order to obtain maximum concentrations results in an increase in specific resistance and, in the future, a reduction in the effectiveness of dewatering.

Aerobic stabilisation, like anaerobic fermentation, also increases the specific resistance of concentrated active sewage sludge and sewage sludge from primary leeches. However, in aerobic stabilisation processes using non-harmed sewage sludge and its mixture with sewage sludge from primary leavers, the return of water may be improved[16].

[16] J. Jansons, Ē. Tilgalis, M. Zviedris, J. Zviedris "Training course for operators of waste water treatment plants and environmental specialists", 2006, Riga

Forms of water and solid-phase particle compounds and their effects on the treatment of sewage sludge

When selecting the type of treatment of sewage sludge, the mechanism for linking solid particles of water and sewage sludge should be understood. Sewage sludge is a suspension consisting of liquid and solid phases. Various undissolved substances, such as solids, dry matter or dried residue, obtained by drying the sample at 105 °C and also containing predissolved substances, which must not be confused with solids which do not belong to dissolved substances, shall be added to the solid phase. It should be specified that drying at 105 °C (a temperature that is minimal but safely above the boiling temperature of the water) is a relatively rapid and convenient method (especially yawn weights), but also approximate at the same time. This method systematically causes errors, both when results are increased and lowered. Higher results are due to these dissolved substances, which remain in the dry residue, while the results are decreasing, since the 105 °C temperature required for the guaranteed evaporation of water inevitably decomposes and/or vaporizes some organic substances, thereby artificially reducing the mass of the dry residue. However, when determining the dry matter of sewage sludge in laboratory conditions using an identical procedure, the reliability of the result is high enough to compare the quality of the dewatering process in different situations.

It is known that sewage sludge is based on water, and therefore one of the most important tasks for the treatment of sewage sludge is to reduce the amount of wastewater sludge by dewatering. Sewage sludge or sewage sludge water has several types which have different links to solid particles (Figure 20):

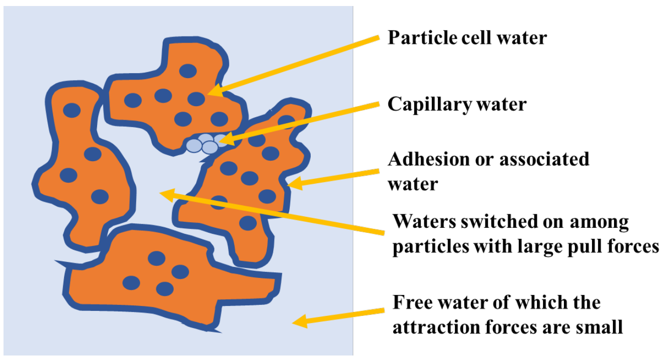

Figure 20. Types of water in sewage sludge

The largest portion of sewage sludge water is among the solids as free water. It can be separated by gravity by sealing the sewage sludge. Where there is a short distance between the particulate matter, surface tension attracts capillary water. It is difficult to separate the capillary water by dissolving the sewage sludge. Adhesion and cell water can only be separated by drying.

This section deals with techniques for the treatment of sewage sludge, which do not include the destruction of the housing of cells. Ultrasound, high-voltage, thermal hydrolysis, biochemical techniques or cavitation pumps are used to disrupt cell casings. As a general rule, such techniques are used to increase the extraction of biogas. None of these techniques is used in Latvia, so when looking at the possibilities of dewatering sewage sludge, it is considered that cell casings are not broken. The exception is the classical mesophilic technology biogas station operating in the WWTP of Riga, the specific nature of which will be briefly examined in the future. The water between particles can be separated by breaking down the cell-shaped structure, which makes the water practically turn into a part of the free water.

The smaller the particle size, the finer the structure of the sewage sludge, the more the sewage sludge contains more colloidal particles and the harder it is to dewater them.

In more detail, it should be concluded that the structure of the water mixture is more complex. Three main factors may be identified:

1) Micro-organisms are diverse. **The biocenosis of sewage sludge** consists of bacteria (including *filamenates, protozoa, metazoa*), algae and fungi. Each of these types includes different types, depending on the composition of the wastewater and the technological characteristics of the purification process. Although the biological purification process itself is based on the two first groups of bacteria and protozoa, the presence of all other micro-organisms may have a significant impact on the sealing and dewatering of sewage sludge, particularly given that the last three groups are multi-cell organisms, and therefore larger and more complex particles of shape. An example of the biocenosis of sewage sludge is shown in the figure.
2) Sewage sludge contains **about 30 % of inorganic substances**, virtually fine sand. There is a large amount of sand entering the wastewater, from gravel with a grain size >2 mm to clay particles with a size of approximately 10 μm (0.01 mm). Properly established sand receivers shall be capable of separating around 70 % of sand – the coarse fractions. Grains of sand, of a size ranging from 0.01 mm to 0.1 mm, shall be proportionate to the size of the micro-organisms and form a significant part of the wastewater sludge to be dehydrated. A grain of sand is hydrophilic, similar to micro-organisms, but the mechanism of shaping its surface charge is completely different, and a grain of sand can result in a negative surface charge as a result of cross-friction. Opposing surface charges and direct adhesion of organic matter to the hard surface of the grain lead to a sustainable compound.

   Neither settling nor centrifugal separation contributes to effective separation of grains of sand from organic mass, although their density varies significantly.

   The presence of a harder and more abrasive fraction in the dry mass of sewage sludge is detected after complete drying, but it is best to verify the quantity of sand and the size of the grain by incineration of the dried mass.

3) Biological activity of micro-organisms results in a variety of **biochemical reaction products,** commonly known as non-cellular polymeric substances (eng. *Extracellular Polymeric Substances* (EPS). The EPS can represent up to 10 % of the total organic mass and consists essentially of protein, carbohydrate and humus. As a result of the treatment of different wastewater, the EPS is summarised in Figure 21. According to municipal effluent, EPS consists mainly of proteins, a certain amount of carbohydrates, and altogether accounts for approximately 9 % of the organic part of sewage sludge. This is a significant quantity and has a significant impact on the treatment of sewage sludge.

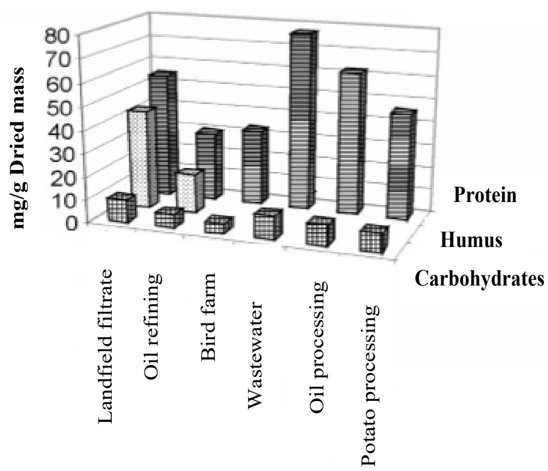

Figure 21. EPS resulting from the treatment of different wastewater[17]

EPS in sewage sludge has a different location and role in shaping the sewage sludge structure (Figure 22). The associated EPS forms a variable density structure around the cell. Such a structure, like a sponge, is capable of attracting significant amounts of water, thereby deteriorating the result of dewatering. By optimising the flooding process before dewatering, measures should be taken to facilitate the dissolution of the EPS, for example by conditioning sewage sludge with enzymes. However, this technology is currently only in the exploration phase.

[17] *The role and significance of extracellular polymers in activated sludge. Part I: Literature review, October 2006, Acta Hydrochimica et Hydrobiologica 34(5): 411–424*

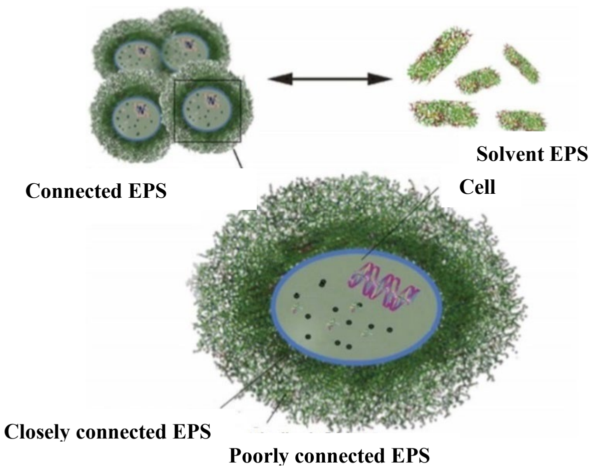

Figure 22. Different types of EPS[18]

In everyday practice, when selecting a floculant, the impact of the EPS is generally not taken into account.

Typical dose of floculant in the dewatering process is approximately 6–10 kg/tDS, i.e. an average of 0.8 % of the dry matter content of sewage sludge, or approximately 10 % by weight of EPS.

In the event of a failed electrochemical process, an EPS, together with a floculant (polysiltrolyte, usually acrylamide groups), can create a colloidal or even jelly-like structure that contains a large amount of water. The extraction of hydrophilic particles of sewage sludge can create a "trap" for a considerable amount of water.

The currently widely practised glass tests for the choice of the best type of floculant do not allow this problem to be avoided, as the amount of water in the upper part of the water glass becomes suitably clean, transparent, but in the slow-sinking mass of sewage sludge is difficult to assess without a precise quantitative analysis.

This is one of the reasons why, even with high quality dewatering equipment and relatively high consumption of floculant, the result of dewatering may prove to be worse than expected.

New practicable techniques to improve the process are expected to emerge in the coming years.

Large amounts of water switched on in EPS structures have a severe negative impact on both filtration-based dewatering methods and centrifugal separation. In order to separate the water from the flop, the filter surface must be subjected to increased pressure associated with the risk of breaking the floods themselves to the size of the filter eye (sometimes observed "maggots" of sewage sludge through the eyes of the filter). On the other hand, due to the high water content

[18] *Yahui Shi et al. (2017) Exploiting extracellular polymeric substances (EPS) controlling strategies for performance enhancement of biological wastewater treatments: An overview,*

of the centrifuge, the notional particle is of reduced density and, consequently, insufficient decomposition forces in the centrifugal gravity field.

These observations and considerations also derive from the average "dry" mass density value of 1040 kg/m^3 used to assess the centrifuge process.

However, it should be noted that it may vary according to different factors:

1) the amount of sand in sewage sludge;
2) the characteristics of biocenosis;
3) the nature of the floculation.

There is a certain analogy here with an index of the volume of sewage activated sludge (SVI). However, there is also a significant difference: if the potential gas release (microburns) has a significant effect, then a mechanical, pressurized dewatering process is much less.

Sewage sludge may be divided into three groups by dewatering:

Easily dewatered sewage sludge dusting sludge	⇨	Wastewater sludge with a high mineral content.
Normally dehydrated sewage sludge	⇨	Sewage sludge from primary guideliners and fermented sewage sludge without special industrial impurities.
Hard-to-dewater sewage sludge	⇨	Activated sewage sludge and aerobically stabilised sewage sludge.

All measures that improve the dewatering properties of sewage sludge are called conditioning. They reduce the capacity of drawing up water and particulate matter and improve the structure of sewage sludge.

The following conditioning methods shall normally be used:

Physical	⇨	Improving the structure by adding ash. Improving the structure by washing sludge.
Chemical	⇨	Formation of flakes by addition of inorganic substances: - lime; - PV (iron) compounds; - Al (aluminium) compounds. Making flakes by adding organic floculants.
Thermal	⇨	Breakdown of the cell skin by heating at high temperature under pressure. Breakdown of the cell skin by freezing.

4.3. Treatment of sewage sludge

The treatment of sewage sludge is a process which makes sewage sludge compliant with certain environmental standards or other quality standards laid down for the treatment and subsequent use of sewage sludge.

4.3.1. Dewatering

Local dewatering of wastewater sludge is the most common processing technology in Latvia's largest cities. Most of the wastewater sludge produced in the WWTPs of Latvia is dehydrated locally, in the wastewater treatment plants themselves.

The most common technological solutions for dewatering local redundant sewage sludge are:

1) centrifuges;
2) filter presses;
3) screw presses.

In practice, there is no single dominant wastewater sludge dewatering technology (Figure 23). Each of the most widespread technologies has its own advantages and disadvantages, and in practice there are no clear guidelines on why the relevant technological solution should be used in WWTP. In large urban WWTPs, where the required voluminous dewatering capacity can only be provided by centrifuges, the high amount of sewage sludge also requires high quality dewatering. In smaller populated areas, the choice is often determined by the cooperation of designers and suppliers of technological equipment for the particular WWTP.

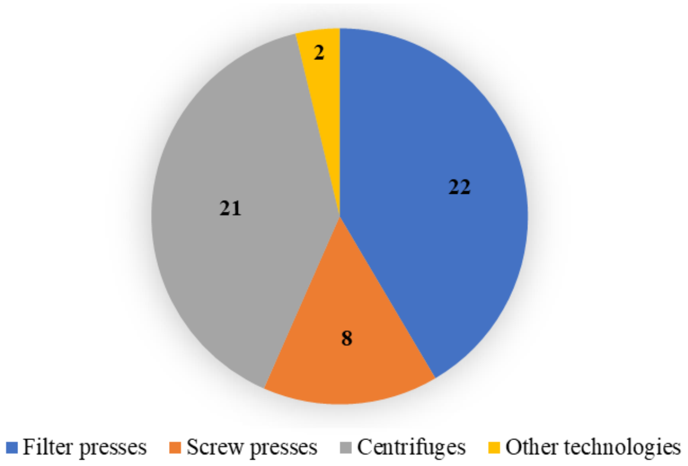

Figure 23. Wastewater sludge dewatering technologies used in Latvia (by number of WWTPs)[19]

[19] Study on waste water sludge treatment technologies used in Latvia (2021), LWWWWA

In WWTPs of similar size sewage sludge is dehydrated by filter presses, screw presses and centrifuges.

In selecting a specific wastewater sludge dewatering technology, account should be taken of a number of factors that may affect both the capital investment of the plant and the cost of operation and the efficiency and longevity of the plant.

1) **Required dewatering capacity**
   Large WWTPs, which dispose of great amount of wastewater sludge and have high recycling costs, should be inclined to a maximum level of dewatering, thereby reducing the amount of sewage sludge to be disposed of and making it possible to choose centrifuges. For other large WWTPs with easy access to composting or other cheap wastewater sludge disposal solutions, the maximum level of dewatering is not so important.
2) **Special features of sewage sludge**
   In certain towns and populated areas with a high impact on industrial wastewater, it may have an impact on the remoteness of surplus biological sewage sludge. There are examples where even with a well-adjusted centrifuge it is not possible to reach a dry matter content of 16 % higher in dehydrated sludge. Use of the screw press or filter press at such locations would not be recommended.
3) **Planned dewatering mode**
   Often, the technological solution provides that the dehydrated sewage sludge is shipped directly from the dewatering plant into a trailer or container. This means that the WWTP needs personnel (a tractor-driver or truck driver) who can regularly export dehydrated sewage sludge. However, in practice, such workers are available only on a daily basis, so the operation of dewatering facilities should be planned accordingly.
4) **Available space**
   Consideration should be given to the possibility of introducing new equipment into existing premises. The size and location of the rooms is fixed in virtually all cases, and it is difficult to change. When planning the replacement of equipment, account should be taken not only of how the new equipment is placed in the existing area, but also of how the dehydrated sewage sludge will be removed from it, electrical feeding solutions, required area for the maintenance of equipment, availability of telfers, etc.
5) **Availability of qualified personnel**
   In smaller cities, high-skilled personnel who are able to fine-tune dewatering plants and compensate seasonal changes in the composition of sewage sludge, etc., are often not available; and the means for purchasing equipment regulation services are limited or there are no means at all. In these cases, the best choice is filtering presses.
6) **Availability, quality and pressure of flush water**
   A lot of belt flush water is needed when filtering presses are used. Where water is not available or is very solid, the use of filtering agents is difficult.

7) **Availability of service**
   Careful consideration should be given to the availability of a service for a potentially installed sewage sludge dewatering equipment, often the trader cannot provide regular, timely and appropriate services.
8) **Total operating costs**
   Some municipal communal enterprises, whose number of customers has significantly decreased, are looking for cheaper alternatives of dewatering solutions currently in use, such as restoring sewage sludge fields and composting the sewage sludge they treat.

Maximum dewatering efficiency and dry matter content may reduce dewatering costs. In this context, it is advisable to calculate in detail the results of dewatering, the costs of energy resources and chemicals and to take these calculations into account when taking decisions and drawing up procurement documentation. Experimental tests for each possible solution should be organised so that the necessary parameters can be calculated more precisely.

4.3.2. Floculants

Successful dewatering is a prerequisite for merging small sewage sludge particles into larger agglomerates – flocules. In order to be able to do this, floculants should be used in the process of dewatering sewage sludge. Their purchase and use in dewatering processes constitute the largest position in the operating costs of dewatering equipment, and when operating a centrifuge, the polymer solution mixed with sludge reduces the abrasive effects of sewage sludge on certain parts of the centrifuge, it also serves as a lubricant.

In the absolute majority of cases dewatering equipment, both centrifuge and presses and filters of various design, cannot function normally without a floculant, polyelectrolyte or polymer.

4.3.2.1. Characteristics of polymers

The chemical composition of the polymer is a commercial secret of each manufacturing firm, but all polymers are based on long polymers with chemically charged (ionized) functional groups attached (Figure 24).

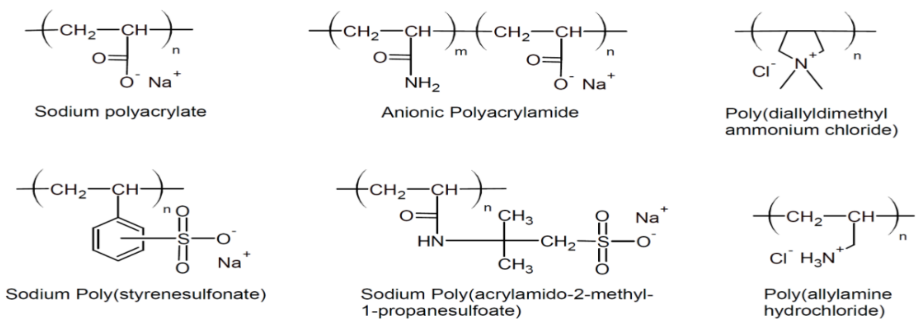

Figure 24. Chemical structure of polymers

There is a certain electrical charge for the active wastewater sludge flakes in the water. When the wastewater sludge flake encounters a counter-charged polymer molecule, the counter-charged particles are attracted and the polymer molecules are able to collect and "freeze" around themselves a relatively large amount of flakes. The process leads to significantly higher aggregates of active wastewater sludge flakes, which are significantly easier to separate from water because they can be filtered relatively more effectively.

The main reason for the polyelectrolyte being most effective in the flotation of sewage sludge particles is the electrical charge of the particle surface.

Particular emphasis should be placed on the impact of solid particle surface charge on flotation. The process of agglomeration of wastewater sludge particles differs from the agglomeration process of other particles (e.g., small grains of sand), since sewage sludge is largely composed of cells on which ion exchange processes take place. This leads to the potential of *Nernsta*. At the same time, a capsule of various organic substances is included in each cell.

Depending on the biological treatment process and the possible pretreatment of sewage sludge particles (bacteria and other micro-organisms) may differ. The nature of total biocenosis, the availability of nutrients and oxygen, the potential for toxic substances and mechanical (centrifugal pumps, etc.) impacts on cell metabolism and the potential of *Nernsta*, respectively. Biological activity and conditions of micro-organisms may significantly alter the formation of non-cellular polymeric substances (EPS).

Seasonal and weather-related factors lead to both water temperature and sand changes in sewage sludge. These parameters also have an impact on the quality of flotation.

4.3.2.2. Choice of polymers

The success of dewatering depends to a very large extent on the reaction between sewage sludge and polymer. The polymer should be chosen correctly for obtaining both the pure filtrate and the maximum dry matter content in the dehydrated mass.

Optimal choice of floculant is a difficult and complex task that needs to be done regularly when different external conditions change.

It should also be noted that although an optimally selected floculant at the basic level provides both a clean filtrate and a maximum dry matter content in the dehydrated mass, this practice may, however, become controversial in order to achieve the maximum result. The rapid formation of very large flocules will guarantee clean and transparent filtrate, but it is likely that in such flocules there will be much water, which will not allow to reach high dry matter content in the dehydrated mass.

The choice of floculant, based solely on glass tests, makes it possible to produce a satisfactory but not optimal result.

It should also be noted that different dewatering technologies are characterised by different mechanisms for particulate matter and water separation (force or filtering applied to the mass centre, residence time, filter pressure and mesh size, etc.).

An optimal selection of floculant can only be discussed in the context of the installation in question.

A relatively common combination of sewage sludge and floculant makes the dehydrated mass highly contagious, causing problems in transportation plants. In such cases it is recommended that a different type of floculant be used. There are currently floculants of many different producers available, so it is high probability to find the right one for each particular case, even though this process can be long and complicated.

Molecules of polyelectrolyte dissolved in water when coming into contact with particles of sewage sludge form "bridge" structures. Using microscopic images, an analysis is carried out to assess the effectiveness of "bridge" formation for the various combinations of sewage sludge and fluorocarbides. Figure 25 shows two samples: to the left, medium-binding structures with an older polymer, and to the right, branched and compact structures derived from the use of new-generation polymers.

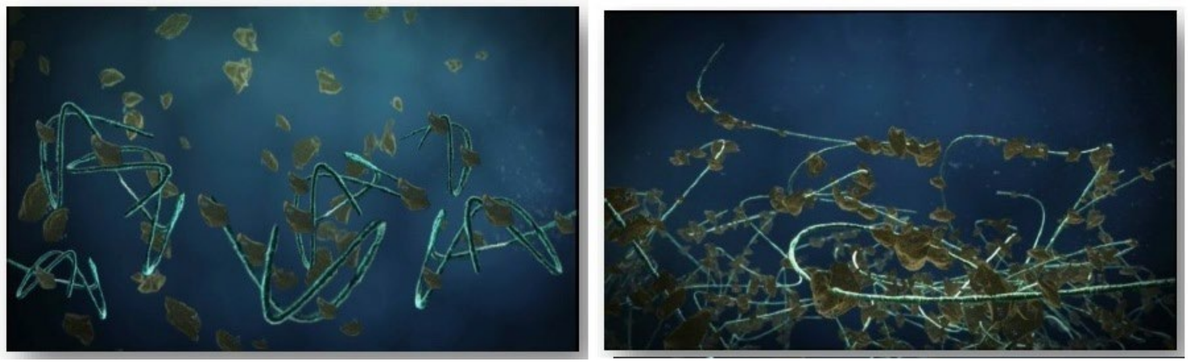

Figure 25. Formation of "bridge" structures. Left – medium, right – branched and compact[20]

4.3.2.3. Polymer types

The amount of polymer required for efficient flotation shall be expressed as a kilogram of the active substance of the polymer per tonne of pure wastewater sludge dry matter. It is called the specific consumption of the polymer (SPC – s*pecific polymer consumption*). Depending on the suitability of the polymer for sewage sludge as well as the tasks assigned to the dewatering process, the SPC may be between 4 and 12 kg/tDS, but more frequently within the range of 6–8 kg/tDS. This means that in dewatered mass there will be less than 1 % of the polymer decomposition products, calculated on the dry matter unit, but if the dry matter content of the dehydrated mass is approximately 20 %, the polymer decomposition products represent less than 0.2 % of the total mass. From this point of view, the impact of the use of a polymer on the mass of sewage sludge to be disposed of can be considered to be insignificant.

Polyelectrolytes are long chain molecules, usually with a molecular weight above 100,000. They are water-soluble molecules with active centres that react with particles of sewage sludge. Manufacturers of polyelectrolytes provide limited information on their composition, and therefore the optimal matching of polyelectrolyte (floculant) and its dose is usually carried out by experimental methods. Currently, floculants based on acrylamine are most commonly used.

[20] www.basf.com

The acrylamin monomer chain forms the “spine” of the active substance of floculant, as the lateral branches are attached to a wide variety of monomers. Most commonly, they are different organic bodies containing nitrogen, but some monomers may also contain sulphur, chlorine, sodium and other elements. The image schematically shows the structure of a branched three-dimensional polymer (floculant).

Polymers are produced in three different physical forms:

1) dry powder;
2) emulsion;
3) aqueous solution.

It is highly likely that any type and condition of sewage sludge is able to accommodate any chemically relevant polymer of those types.

The choice is determined by the method of preparing the solution at the operator's disposal and by the price of the polymer.

Polymers in the form of dry powder are traditionally the most economically advantageous, but when working with them, the most complicated equipment is needed for preparing of the solution.

By ionic charge, polymers are classified as follows:

1) anionic;
2) cationic;
3) non-ionic.

In fact, a certain type of sewage sludge reacts only with a polymer of one type of charge. Non-ionic polymers are rarely used in dewatering municipal sewage sludge. Anionic polymers are suitable in situations when additional treatment with lime or iron chloride is used, which does not take place in Latvia.

Cationic polymers are most commonly used.

Dry powdered polymers

Powdered polymers typically contain 80–90 % of active substance, but it is difficult to identify precisely, so a 100 % concentration of the active substance is notionally used in the calculations. They sometimes contain a lot of dust that makes it difficult to use them.

Dry powdered polymers in water are soluble in a specific way, therefore the qualitative preparation of their solution is not simple. If more monolithic powder is released into the water, the surface of the powder dissolves by creating a glue capsule, which is partly where water diffusion is slow even in the event of intense mixing. A stable structure, so-called “fish eye”, is established and some of the active substance in the polymer is not used because it cannot come into contact with particles of sewage sludge in this way. The preparation unit of the solution (Figure 26) must be such as to ensure that a sufficiently dispersible powder “currents” are in contact with water, and to achieve this, at least 40 minutes of passing time must be observed while stirring slowly.

When storing powdered polymers, a dry environment must be provided. When exposed prematurely to water, the powdered polymer is permanently damaged.

Figure 26. Polymeric Preparatory Unit for the WWTP of Liepāja city[21]

Emulsion shaped polymers

Emulsion-shaped polymers consist of 1–2 micrometer-size drops, each containing a large number of polymer circuits dissolved in water. On the other hand, the drops are interfered with a matrix in the oil phase. The active substance content of emulsion-shaped polymers is usually within 30–50 %. Preparation of the emulsion-shaped polymer solution is simpler than powdered, but the risk of "fish eye" formation exists. Mix node or static mixer must be used. The emulsion-shaped polymer solution must also have a passing time prior to feeding to contact with the sludge, at least 15–30 minutes.

In no case shall water be permitted to enter the emulsion tank.

Polymers of aqueous solution

This is a relatively new form of polymers. It is developed in the context of the use of more environmentally friendly substances in the treatment of sewage sludge. The aqueous solution polymer is liquid, its viscosity is similar to that of other polymers' aqueous solutions, approximately 2000 cP. The amount of the active substance in polymers of the solution form is within the limit of 20–40 %. The active substance is already dissolved in water, so it is very easy to dilute it to the appropriate concentration. No special equipment is needed with tanks, a static mixer *in the in–line* process is enough. This is considered to be a very prospective formation of the aqueous solution.

[21] *"Liepāja Water"Ltd. archive*

4.3.2.4. Selection of solution concentration

In order to ensure effective mixing of the active substance of the polymer with sludge, a low-concentration aqueous solution is prepared before feeding to the mixing point. The concentration range of 0.05–1 %, but in most cases it is 0.15–0.5 %. The main concentration selection criterion is the viscosity of a sufficiently low solution which ensures a smooth mixing of sewage sludge and polymer solution and the reaction of sewage sludge particles and polymer molecules. (The viscosity of sewage sludge in the range of dry matter concentrations to 4 % of water viscosity is very minimal and therefore the concentration of the polymer solution is the determinant). However, clear determining the optimal concentration of the solution is difficult, the viscosity of the various types of polymers at the same concentration varies significantly. It is not recommended to exceed the viscosity value of 1000 cP polymer solution.

The second factor that should be taken into account is that if the dry matter concentration of sewage sludge is relatively high before dewatering, approximately 3–4 %, and the polymer solution is low, approximately 0.1 %, a significant amount of water is supplied with the polymer sludge, relatively these may be 20–25 %. It reduces the lifetime of sewage sludge in the dewatering plant and may negatively affect the result of dewatering.

The optimal concentration of the polymer solution is to be determined experimentally and individually.

If warm water (approximately 30 °C) is available at the WWTP, it is recommended that it be used for the preparation of the polymer solution, as the process of dissolving the polymer will be more homogeneous, the active substance will be used more rationally and savings of up to 15 % of the polymer concentrate are expected. The maximum allowable water temperature for polymers of different types is different but not less than 30 °C.

4.3.2.5. Examples of preconditioning machines for polymer solution

The quality of the preparation equipment for the polymer solution is essentially determined by:

1) exact dosing of concentrate;
2) effective primary mixing;
3) sufficient treatment time and appropriate mixing;
4) protection of the concentrate against moisture, prevention of condensation;
5) constant concentration in the supply tank or zone, also during the preparation of a new portion;
6) safe automatic control;
7) easy and ergonomic concentrate loading.

The operating principle distinguishes portions and flow-through preparation systems.

Preparation apparatus for the polymeric solution of the type preparation of portions (Figure 27) is intended for automatic preparation of the polymer solution, both of powdered and emulsified polymeric concentrate. Mix the solution into a vortex cone. The powder is supplied from the bunker by means of a two-bolt conveyor, while the powder is loaded into a bunker with a vacuum conveyor.

Figure 27. Preparation apparatus for polymer solution[22]

A mixing unit of a polymer solution designed and manufactured in Latvia (Figure 28), intended for handling the preparation of portions. The equipment shall be so manufactured that the dosing of the powder takes place in a closed, moisture-protected environment. The equipment is equipped with a powder nozzle heater.

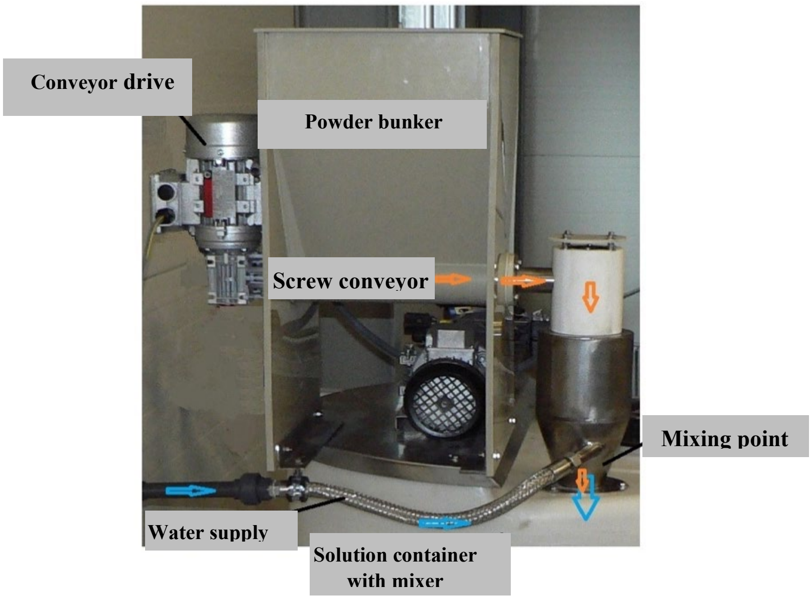

Figure 28. Preparation unit of powdered polymer solution

[22]www.prominent.us

Preparing and feeding system for the solution of the flow-through polymer from the emulsified concentrate is shown in Figure 29. The emulsion is dosed at the mixing point with the peristaltic pump for variable yield. The water supply is controlled by means of a rotometer and valve. There is a small airtight volume of the solution. The supply to the mixing point shall be operated by the pressure of the connected water supply. An electrical mixer is fitted.

Figure 29. Flow-through polymer dosing unit[23]

Polymer concentrate and water supply *in-line* equipment with a mixing unit in the form of a static mixer is shown in Figure 30. The equipment is intended for use only in working with polymeric concentrate of aqueous solution, where it is not necessary to treat the solution. The equipment is much simpler than the others.

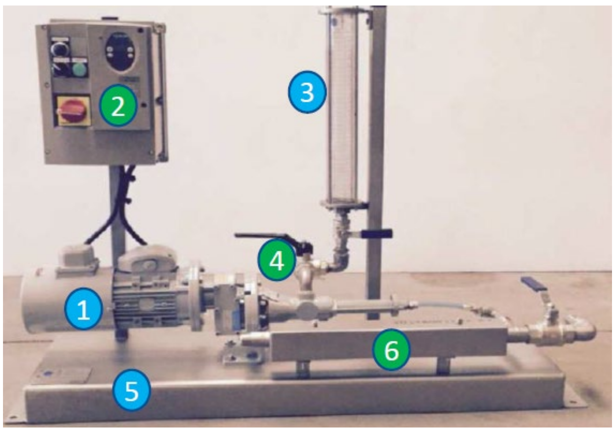

Figure 30. In-line polymer dosing unit

4.3.2.6. Practical recommendations and recommendations

If the comparison and selection of polymers of different shapes is divided separately, then:

1) The quality of floculation is determined by the active substance, in this respect it is not important in what form it is used.

[23] www.prominent.us

2) In order to ensure mixing with sludge, all forms of the polymer must be diluted with a large amount of water. There is also no difference in that respect.
3) The absolute majority of active substances used today are initially in a solid state. Therefore, the powder also contains the highest concentration of the active substance, close to 100 %, respectively, the product costs are the lowest in this form. Due to the convenience of intervention (see below) manufacturers also offer an emulsion form where the active substance is first dissolved in microscopic water drops, then mixed in oil emulsion. This technology is not cheap, of course, so the active substance in the form of emulsion is much more expensive. Often a kilogram of powder costs as much as a kilogram of emulsion, but the active substance in the powder is twice that. Sometimes the user even misses this fact. A more expensive product is less popular, so traditionally producers offer less choice for the product in the form of emulsion, which makes it difficult for the customer to optimize.
4) Water solutions are just beginning to appear, the choice is very limited, it is still “exotic” and is gradually introduced. If this form gains popularity and there is a variety, it will clearly be the product of the future. So far, there is no clarity on price levels. A notional minus is also the need to transport a lot of water, since the active substance in this form is also 20 %.
5) It is more difficult to make a qualitative solution from the powder than from an emulsion or, in particular, an aqueous solution. Therefore, the powder preparation equipment (polymeric) will always be more sophisticated, larger and more expensive.

For small WWTPs, where the consumption of the polymer is small, it makes sense to save at the expense of the equipment because the prices of the equipment are not proportional to their productivity. You can buy a simple *Polymore* machine or a slightly better local product (with the method of preparing the portion), and the savings will be so great that the use of a more expensive polymer will not exceed the entire life of the installation.

For big WWTPs, it is the other way round. There is an additional factor: the market for small WWTP polymers is monopolised, the choice of polymers is small, so it is easier to find optimal powder and the choice for the powder is also small. The supply of simpler and cheaper powder machines is also emerging, respectively.

6) Day-to-day handling of powder can be unpleasant because of dust. A respirator should be used when filling a bunker with your hands. Therefore, in addition to powder machines (and their costs) there should be a vacuum conveyor to a bunker, which is not always the case. Sometimes suction of powder through a plastic tube creates a strong static charge, 100 V and more. In such a case, adequate grounding must be provided.
7) Large, basically powder-based machines are increasingly fitted with an emulsion pump and can operate in both shapes. If this is not the case, it is very easy to adapt the powder machine for the use of both materials.

8) The powder may be stored for a longer time and in lower temperatures.;
9) If the quality of the product is low, it can be seen immediately in emulsion – heterogeneous mass, residues. The powder manipulation is easier to hide. There are certain cases when the powder is mixed with boiling salt, which also increases water conductivity, so there is a floculant to some extent. But for this to happen, intentional malpractice must be taken, but for emulsion, quality problems are more common than accidental failures.
10) The oil contained in the emulsion has a negative impact on the quality of the dehydrated mass, particularly when used in agriculture.

In general, on the basis of practical experience, it should be concluded that practice is **in favour of the use of powdered polymers**, but it is also desirable to provide for the possibility of a temporary use of emulsion, or in case of a sudden change in the properties of sewage sludge or a seasonal variation try a new polymer.

4.3.2.7. Polymer price

The price of the polymer may vary greatly and is based on the following factors:

1) **Type of polymer**
   Liquid polymer concentrate (50 %) converted to a dry (100 %) polymer, is usually more expensive than the dry polymer of the same brand.
2) **Polymer brand**
   Modern polymers, such as so-called cross-linked polymers, are more effective than straight-chain polymers; their dose may be lower, but they are significantly more expensive. In each case, individual checks must be carried out and the optimal polymer brand/price must be ascertained.
3) **Quantity of polymer supplied**
   In practice, WWTPs of large cities that buy larger amounts of polymer receive more favourable price offers from producers than small WWTPs.

The price of the polymer may vary between 1.35 and 4.36 EUR/kg with an average price of 3.00 EUR/kg.

The preliminary consumption of the polymer is presented below for each dewatering technology as it is more dependent on the type of sewage sludge and its remoteness than on the operation of the dewatering plant. Laboratory measurements and full-spectrum tests of sewage sludge and polymer should be carried out in order to obtain reliable information to select the most suitable polymer and is dosage, as well as to optimise the operation of the dewatering plant regardless of the wastewater sludge dewatering technology.

4.3.3. Dewatering methods and equipment

4.3.3.1. Compaction/confinement

After the treatment of wastewater, the water content of sewage sludge is between 97 % and 99.5 %. By sealing sewage sludge, it increases the dry matter by reducing the water content with low energy consumption. The sealing of sewage sludge may be used both for pretreatment for fermentation and for pretreatment for dewatering, which operates without a fermentation equipment.

In Latvia, wastewater sludge for dewatering is usually taken from the recirculation loop of sewage sludge. In this case, the concentration of sewage sludge is approximately 1 % and most wastewater sludge dewatering equipment is designed to work directly with that concentration of sewage sludge. However, a number of WWTPs use the sealing of sewage sludge, which allows for a significant reduction in hydraulic load in wastewater sludge dewatering equipment.

Three main methods can be distinguished for the sealing of sewage sludge:

1) gravity sealing in static clarifier;
2) gravity sealing in the gusher with a rotating skateboard and an overflow channel;
3) mechanical sealing in a special equipment.

Primary sewage sludge, redundant sewage sludge and their mixture can be treated using gravity and mechanical sealing techniques. Since the mixture of primary and superfluous sewage sludge deposits more effectively than the excess sludge alone, gravity sealing is more effective.

In selecting an optimal level of sealing of the active sewage sludge, account should be taken not only of the type of sealing, but also of the composition of the active sewage sludge, which in turn depends on the composition of the effluent to be treated, the level of effluent treatment, the conditions for preparation, etc. For example, active sewage sludge in the case of incomplete biological purification is sealed much better and faster than in the case of a full degree of biological purification. The mixture of sewage sludge from aeration tanks smokes better than the sewage sludge from secondary landing tanks.

The mixtures of sewage sludge in each WWTP have different characteristics, so it is recommended that a full-scale laboratory test be carried out to find the optimal results and costs.

By reducing the organic matter content in the solid phase of the active sewage sludge, a higher level of sealing of the activated sewage sludge can be ensured, thereby also contributing to an increase in the density of the activated sewage sludge. While cleaning municipal and industrial wastewater, the composition and properties of the active sewage sludge can vary rapidly, resulting in changes in their ability to compress. Sometimes the sealing of extra active sewage sludge is carried out together with sludge from the first landing tanks. In such a case, mixing of the mixture and a reduction in the water content shall be achieved.

4.3.3.2. Multi-step concentration/dewatering

This section deals only with multi-stage mechanical wastewater sludge treatment schemes established as WWTP structures. The belt sewage sludge presses, which also use two-stage concentration/dewatering at all times, will be examined separately.

The objective is to wet sewage sludge formed in the wastewater treatment process into the driest possible mass, while maintaining a maximum percentage of dry matter.

In many cases it is rational to divide this process into two parts, namely concentration and dewatering.

The main objectives of this breakdown are two: firstly, to obtain a higher dry matter content of the final product and, secondly, to reduce the consumption of dewatering resources by allowing smaller capacity dewatering equipment to be used and electricity consumption to be reduced. Returning to the sections on separate dewatering equipment can demonstrate the benefits of submerging sewage sludge. During the centrifugation process, a reduced amount of water in the incoming sewage sludge reduces the amount of energy needed to give the fluid a rotation movement and increases the lifetime of sewage sludge in the centrifuge, thereby improving the quality of separation (or a smaller-size centrifuge may be chosen). In turn, filter presses of different design can reduce the area of the filter surface, i.e., the size of the installation, including the use of flushing water. In all cases, smaller size delivery pumps may be used. In practice, the only potentially negative factor is the difficulty of smoothly mixing with the floculant solution due to greater viscosity.

The preferred performance of the various premeditating plants is up to 4 % of dry matter.

In the case of a gravity wearer, it is practically impossible to exceed this limit. Mechanical mixing equipment as thickeners of a rotary sieve must be properly regulated.

In most cases, wastewater sludge is discharged from the biological purification process directly after being in secondary clarifiers, separating the flow intended for dewatering from the recirculation flow. It is assumed that the concentration of such wastewater sludge is 0.8–1.2 %. In each case, it depends on the concentration of sewage sludge in the biological treatment system and the ratio of the wastewater sludge recirculation flow to the flowing effluent flows. Consequently, the concentration of wet sewage sludge may vary within a wider range of approximately 0.6–2 %. If the wastewater sludge volume index (SVI) is low enough and the sedimentation is rapid, as well as the dimensions of the gusher are sufficient, it is possible to reduce the recirculation flow at the time of discharge of excess sewage sludge, thereby increasing the concentration of wastewater sludge to be dehydrated before the dewatering equipment. This method is used in practice and can actually be considered as one of the two-step methods of concentration/dewatering.

Gravity wearers

The gravity wearer shall be created as a tank with a capacity corresponding to the duration of the 15–30-minute sewage sludge in the tank, the diameter of which shall be up to two times the depth. It is recommended that the tank be equipped with a very slow-rotating mixer which destroys very large piles of sewage sludge by encouraging smooth sedimentation. Such a concierge may be established for both the full and partial flow of recirculation. A full-flow sewage sludge enabler is more common, as this scheme is simpler and no additional pumps and pipelines are needed. However, it should be noted that the recirculation of sewage sludge is ongoing, but the process of dewatering sewage sludge is usually organised within a given hour of the day, so the concentration of sewage sludge to be transmitted to the dewatering equipment may change. Using this technology, it is highly desirable to install *an on-line* sewage sludge concentration meter in order to automatically adjust either the supply of a constant amount of dry matter to the dewatering plant or the corresponding supply of floculant solution. The gravity wearer works without the addition of floculants.

Mechanical thickeners

The design and functioning of the mechanical attachment equipment itself is shown in the relevant section. Only aspects of the overall operation of several installations are examined here.

Mechanical action thickeners shall be used relatively rarely when implementing the first degree of concentration of sewage sludge prior to dewatering in a centrifuge. As a general rule, such a solution is due to the lack of space or difficulty in creating a large-scale gravity thickener, as well as the reluctance to install a large-size centrifuge. The only advantage of such a solution is relative compactness. Mechanical action (e.g. rotary sieve) thickeners require a floculant solution, which leads to both higher total reagent consumption and a difficult to optimize re-flotation process at the centrifuge inlet. Washing water is also required for the operation of the sieve. It should also be noted that the discharge of concentrated sewage sludge from the rotary sieve thickener is not uniform and requires an intermediate container with a mixer to offset the flow. During the process of mixing sewage sludge, such an installation must not only vary in the flow of concentrated sewage sludge, but also in the concentration of the sewage sludge, so that the intermediate container must be sufficiently large to offset these fluctuations. This, in turn, greatly undermines the advantage of the scheme mentioned above, namely compactness. In practice, such a scheme could only be justified in WWTPs with separate primary leeches where very low levels of biological waste water sludge are expected to occur.

Also, diagrams with large cross-vessels to be aerated are created. Although intensive aeration contributes theoretically to mineralisation of sewage sludge and could improve its remoteness in a centrifuge, the benefits observed in practice are too minor to justify the construction of a relatively complex structure and the energy consumption for aeration.

Two-stage concentration/dewatering is more common in the formerly constructed WWTPs, as the centrifugal force (*G–force*) produced by older models was significantly lower, with a rotation speed of 2600–2700 rpm. (in modern appliances, 3500–4500 rpm./min, up to 5600 rpm./min in small-scale centrifuges). In such plants it was not possible to degrade sewage sludge from the initial concentration of approximately 1 % to the desired content of approximately 20 % dry matter in a single-stage process. These centrifuges were constructed for the concentration of incoming sewage sludge around 3 %.

Summary

A two-stage thickening/dewatering scheme with a gravity thickener without the use of floculant is considered to be a rational and desirable solution, particularly in view of the increasing importance of reducing energy consumption.

In the absence of a separate concentration tank, it is recommended to use manipulation of the wastewater sludge recirculation capacity to locally increase the concentration of sewage sludge prior to dewatering, unless it does significantly impair the biological purification process.

The operation of two mechanical equipment (e.g., a rotary sieve thickener and centrifuge) in a series is not desirable. If any external factors indicated such a solution, better consider setting up the belt press in such a way that the pair of equipment is combined into one with a one-off total flotation.

4.3.3.3. Compaction using gravity force (static clarifiers)

Compaction, based on the use of gravity force, is a simple way to reduce water content in sewage sludge with low energy consumption. Sewage sludge is pumped into a round tank equipped with a slow-rotating rake-type mechanism that breaks the linings of sewage sludge particles, thereby increasing the level of landing and sealing.

Another objective of gravity sealing is to achieve significant hydraulic buffering capacity (up to three days) between the wastewater flow and the process of treating sewage sludge.

Gravity sealing requires a separate pool – usually a round-shaped concrete basin. The diameter of a typical pool is 8–20 metres. The gravity sealing unit continuously acts as a sealing agent and a buffering tank. The gravity cracker can be placed under the open sky. Depending on the landing properties of sewage sludge, floculants should be added in some cases, but they are not recommended for the sealing of primary sewage sludge. Gravity sealing can reduce the total amount of sewage sludge by 90 % of the original volume, while energy consumption is very low.

Gravity sealing in the gusher with rotating skateboards

In seals with a rotating skateboard (Figure 31) and an overflow channel, the excess sewage sludge is transmitted to the settlement, not parts as in the case of static compactors, but continuously.

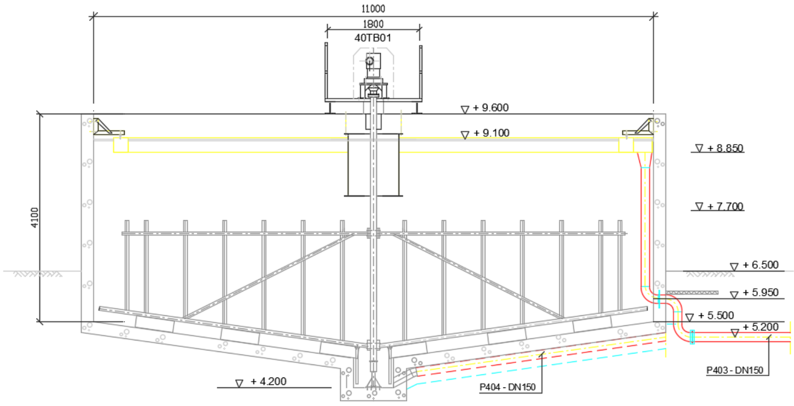

Figure 31. Cross-section of gravity cracker with rotating skateboard

The rotating skater drives the compacted sewage sludge into the middle of the cone underlying the tank, from which they are pumped for dewatering. Clear water flows into the top of a tunnel equipped with overflow teeth and is discharged to a local pumping station.

Fitness

All types of sewage sludge can be crushed by gravity. Not all dewatering equipment is optimized for handling compacted sludge, usually optimized for working with 1 % sludge.

Dewatering result

Depending on the volume index of sewage sludge (i.e., the sedimentation properties of sewage sludge), such a sealing agent is able to seal sewage sludge up to 3–5 % of dry matter.

Operation and maintenance

Cleaning or maintenance is usually required every 1–2 months, but in case of sewage sludge swelling, the sealing should be cleaned more frequently (depending on the frequency of occurrence of the swelling problem, which should also be resolved for other reasons).

Environmental aspects

Environmental aspects are linked to potential unpleasant emissions of odorous gases into the air. The emissions can be reduced by chemical treatment of the pool content with calcium hydroxide (a method suitable for small and medium-sized installations). In densely populated areas or in the vicinity of residential buildings, the pool must be covered with a light-structured roof and ventilation must be provided to prevent the emission of abnormally odorous gases.

Costs

Capital costs mainly depend on the size and condition of the bottom of the pool. The emission of odours increases costs. Operating costs are low because electricity consumption is low and the lifetime of the equipment is between 20 (for equipment) and 40 (for tank) years.

Advantages and disadvantages

The main disadvantage of a compactoris its relatively expensive construction.

4.3.3.4. Mechanical sealing

The method of mechanical sealing normally treats excess sewage sludge. It is possible to mechanically seal the mixture of primary sewage sludge or primary sewage sludge and wastewater sludge. As a general rule, plants with a small primary gusher are used for the mechanical sealing of sewage sludge, as well as for cases where sewage sludge is not fermented. Mechanical sealing is to be applied in small and medium WWTPs using it as pretreatment for direct dewatering or fermentation.

Dewatering result

Unlike other compaction methods, mechanical sealing requires the addition of a polymer solution into the sludge dewatering equipment, which significantly increases the sealing process, so mechanical sealing is mainly used where dewatering up to >15 % of the dry matter is not necessary. However, the substrate must be well pumped and in suitable consistency for further use, for example, if the compacted sewage sludge is then intended to be sliced into methanes.

Technology

Several solutions are available in mechanical sealing of sewage sludge. One of the simplest is an almost horizontal tubular rotating sieve (Figure 32) through which water is spilling, but it holds sewage sludge. As the sieve is slanted, sewage sludge moves through it to the lower end of the sieve and is further transmitted to either dewatering or somewhere else.

Figure 32. Sewage sludge sealing – rotating sieve

Other types of mechanical sealing equipment, such as an oblique, rotating sieve (Figure 33), are also used. A special distribution mechanism distributes sewage sludge along the surface of the sieve, while the wedging system shifts pips of sewage sludge from side to side, allowing them to come into contact with a fresh, clean sieve surface. At the end of the circle, a static skater strips sewage sludge from the surface of the sieve and leads it to the compacted sewage sludge pump. The advantage of the machine is its compactness: being relatively efficient, it takes up little space.

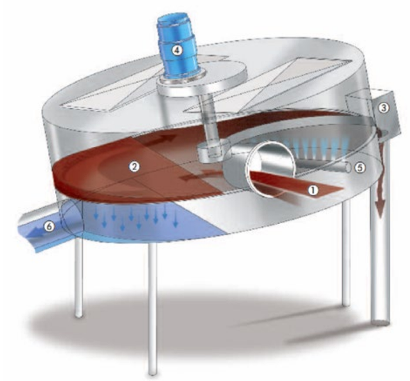

Figure 33. Wastewater sludge sealing – slanted rotary sieve[24]

There are also exceptions when mechanically compacted sewage sludge is subsequently dehydrated and exported. In Latvia only one WWTP works in this way.

[24] www.huber.de

4.3.3.5. Centrifuges

A horizontal centrifuge with continuous supply and effluent sludge output is a standard centrifuge type. Centrifuge models with a high multiple of gravity “g”, which provide high dry matter content, are preferred.

Fitness

Centrifuges are usually used for dewatering fermented or aerobically stabilised sewage sludge, but they also allow other types of sewage sludge to be dehydrated. In the past, centrifuges were used mainly in large WWTPs, but they are increasingly used in small and medium-sized WWTPs today. Centrifuges are compact and closed equipment, their work is clean and safe, and small models are also available today. Mobile centrifuges to be installed in a truck are also manufactured, which can be used for a number of small WWTPs, providing a cost-sharing between water holdings.

Advantages and disadvantages

Benefits	Disadvantages
Centrifuges are able to provide a dewatering rate of sewage sludge >20 % dry matter	More expensive than filtering presses and at about the same price as Bolt presses
Even if the sewage sludge is poorly mingled and/or the polymeric mark is not optimal, it is nevertheless capable of ensuring a high degree of dewatering of sewage sludge	Consumes many times more electricity than analogue screws press or filter presses of same efficiency
Polymer consumption is lower than for film presses or screws presses	Causes great noise and significant vibrations
Widely used technology	Very qualified service required
Suitable for large WWTPs, as they are capable of producing high yields	Spare parts are expensive
	Maintenance costs are high

Technology

The operation of the centrifuge (Figure 34) is based on the varying density of sewage sludge and water. The sewage sludge is slightly heavier than water (a density of approximately 1.,04 g/ml), and is therefore gradually precipitated in the bottom of any vessel/tank by gravity. If gravity is increased, for example by increasing the mass of sewage sludge, sedimentation is taking place more quickly.

Polymer-mixed sewage sludge is supplied in a decanter centrifuge rotating tank. Centrifugal force carries sewage sludge to the outer walls of the rotating tank. Inside the tank there is a screwed conveyor that rotates at a slightly different speed and gradually moves the mass of precipitated sewage sludge onto the narrower part of the cone (i.e. beach) of the rotating tank. At the end of the cone, the centrifugal force throws the dehydrated sewage sludge out of the cone through special openings.

The space required depends on dimensions, normally: width 2–5 metres, length 7–15 metres, height 3–6 metres, including the space required for maintenance. Centrifuges can only be installed indoors.

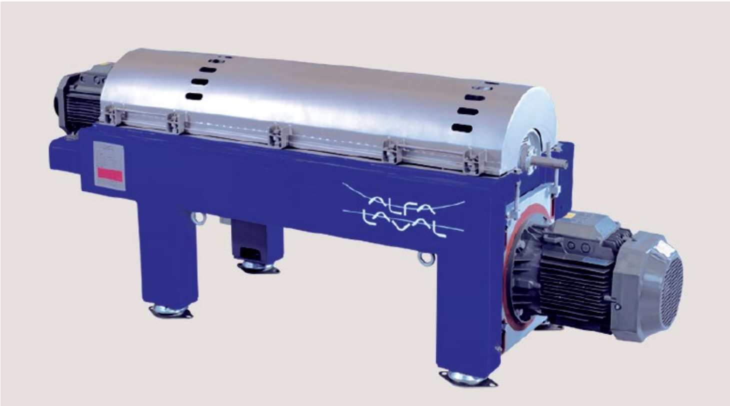

Figure 34. Decanter centrifuge[25]

General description of decanter centrifuge

Decanter centrifuge is a horizontal centrifuge with a monolithic wall rotor with a cylindrical and conical part designed for continuous dewatering of the precipitate. The liquid phase freely passes through the adjustable openings at the cylindrical end. When changing the opening inserts, the level of the precipitate to be processed in the rotor is regulated. The dry (dehydrated) mass is removed by means of specially protected holes at the conical tip. Parameters describing typical centrifuges are summarised in Table 18, and the essential details are shown in Figure 35.

[25] www.alfalaval.com

Table 18

Centrifuge Characteristics (example)

No.	Name	Parameters
	Main dimensions	
1.	Rotor inner diameter	353 mm
2.	Diameter/length ratio	1: 4
3.	Mass	2200 kg
	Main technical data	
4.	Rotor rotation speed (main drive)	up to 4,000 rpm
5.	Maximum centrifugal force factor	3400 x g
6.	Yield	5–25 m^3/h
7.	Yield of net dry matter	up to 500 kgDS/h
8.	Concentration of dry matter in the intake	average 1 % (mass/mass)
9.	pH:	6–8 (neutral)
10.	Mineral content in dry matter	average 35 % (approximately equal TO SVI = 100 ml/g)
11.	Dry matter content in dehydrated mass	on average 22 % (20 % guaranteed, at the given sediment properties in the intake)
12.	Separation efficiency	at least 97 %
13.	Floculant consumption	– 8 kg/tDS
	Materials	
14.	Parts of the rotor in contact with the product	Stainless steel 1.4470, 1.4462, 1.4571, 1.4301
15.	Other parts in contact with the product	Stainless steel 1.4571, 1.4541, 1.4301
16.	Parts not in contact with the product	dyed steel
	Recovery system	
17.	Main drive	Asynchronous electric motor, 22 kW, with keel-belt drive
18.	Conveyor drive	Proprietary propulsion system with multi-stage planetary reducer and braking electric motor, frequency changer and toothing drive
19.	Management system	A *PLC*-based control system that controls drive frequency changers and ancillary equipment. Operator panel, interface for SCADA connection
	Anti-wear protection	
20.	Conveyor thread	Coating of tungsten carbide on the front edge
21.	Intake openings	Solid pile inserts
22.	Rotor interior	Vadules in the direction of mass flow
23.	Dry mass outlet	Solid pile inserts

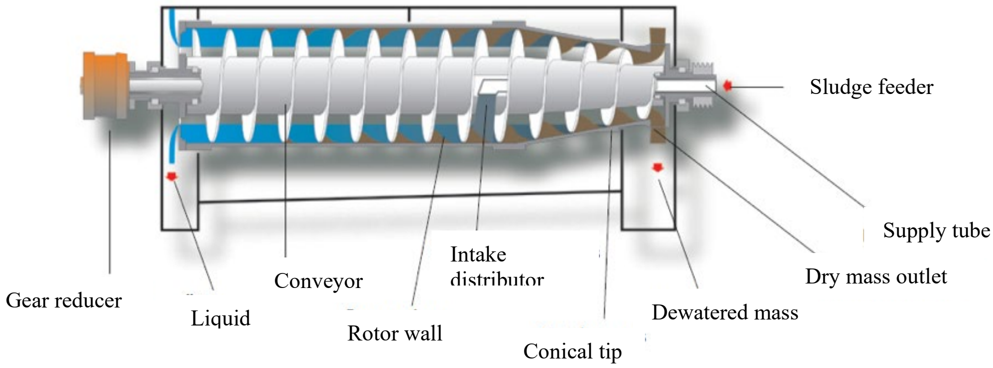

Figure 35. Basic components of decanter centrifuge

Main aspects of dewatering process of the decanter centrifuge

One of the most efficient models of the process of dewatering excess sewage sludge is the splitting of dry fractions (dry matter) and water using differences in their density in an artificially created centrifugal "gravity" field. It is the only dewatering method which creates a mass-centered decomposition and does not require any filter material to be used, thus allowing a much higher force to be applied immediately to the entire amount of sewage sludge to be treated.

The artificially created centrifugal "gravity" field is defined as a number expressing the number of times the centrifugal force exceeds the gravity of the earth and the turn of the free-fall acceleration.

The centrifugal force shall be expressed as a product of normal acceleration and mass of rotation. Normal acceleration a_n is expressed in (3):

$$a_n = \omega^2 \times r,$$

where

$\omega = 2\ \pi n/60$ – angular speed, s^{-1};
n – rotary speed, rpm;
r – radius, m.

The rotation speed of decanter centrifuges of different structures is reaching 5600 rpm, while the radius of the rotor is usually between 0.1 m and 0.25 m. Rotation rates of centrifuges with smaller diameter are generally higher than for large centrifuges.

For the dewatering of excess sewage sludge, equipment of 3000 g or more of centrifugal "gravity" shall normally be used.

The relationship shows that the centrifugal force, or "gravity", is variable and dependent on the radius of the centrifuge, as opposed to a simple settlement process. The integration of the forces of such a hydraulic system may result in the extraction of water from a notional porous sewage sludge flop environment of another important dewatering process parameter. For a medium diameter (approximately 400 mm) and medium-speed rotating (3500–4000 rpm) centrifuge, pressure on the outside wall of the rotor may exceed 10 bar (it also depends on the level of fluid in the centrifuge, which will be viewed below).

The pressure value of 10 bar is significantly higher than, for example, the bolt in the press and is considered to be an advantage of centrifuge.

Capacity of centrifuge

When looking at the capacity of the centrifuge, it should be noted that its value has three main limiting factors, such as hydraulic yield, net dry matter yield and the capacity of sewage sludge to decompose at the time it is in the centrifuge.

Hydraulic capacity

The maximum yield of the fluid (water) supply is when the entire liquid is able to pass through the openings of the filtrate and the centrifuge rotor is not overflowing.

This is always the highest yield value, it gives an approximate picture of the size of the centrifuge, but it has no direct connection with the ability of the centrifuge to separate sewage sludge. The manufacturer shall indicate this because this value does not depend on the characteristics of the previously unknown sewage sludge. As shown in the example, the maximum value is 25 m^3/h (Table 18). Most often, by specifying the specific conditions in WWTP, in the case of that capacity, such a centrifuge size will not be able to provide satisfactory dewatering quality, therefore the corresponding reserve should be assessed when selecting the centrifuge.

Yield of net dry matter, dry matter transport yield

It is the maximum capacity of the centrifuge conveyor and its propulsion to transport the mass of the separated concentrated sewage sludge (notionally referred to as dry matter) to the discharge holes (ports) of the dehydrated mass.

The conveyor drive is implemented using a planetary reducer, electric motor and frequency converter. To protect the planetary reducer from overload, the automatic control system limits the torque generated by the electric motor. This limitation of yield actually means the torque limit for the conveyor drive shaft, but in the knowledge of the geometry of the conveyor and the characteristics of the average sewage sludge (likability, viscosity of the mass), the manufacturer may express that limitation of yield in such a readily discernible form. With sufficient precision in this case, it can be considered that all the dry matter contained in sewage sludge is in the dehydrated mass to be transported by the conveyor, so that the required amount can easily be obtained as a multiplication of the yield and the concentration of sewage sludge. The example (Table 18) shows that this type of restriction becomes limited only in the case of previously concentrated sewage sludge, but in the case of digestat, when a gravity compactor or biogas plant is used. The excess sewage sludge contains approximately 1 % of the dry matter directly from the recirculation contour. Following operational experience (further analysis of process parameters), it can be said that the technically and economically justified capacity of the centrifuge considered in the example is approximately 10 m^3/h and only results in 100 kgDS/h, which is significantly below the limit imposed by the manufacturer. On the other hand, such an unloaded conveyor drive often makes it difficult to control torque. Practically, it is only working in fixed differential speed mode, and electrical characteristics of the conveyor drive give only approximate information on the quality of dewatering (detailed information on this relationship is provided in the section on the electrical systems of centrifuge).

The capacity of sewage sludge to decompose over the time it is in a centrifuge

Knowing the geometrical characteristics of the centrifuge rotor and the flow of sewage sludge supply, it is easy and with satisfactory precision to calculate the lifetime of sewage sludge in the centrifuge.

Most commonly, rational centrifuge yields are limited by the capacity of sewage sludge to decompose over time spent in a centrifuge, which the manufacturer most frequently does not indicate because it depends directly on on-site regulation of the centrifuge and on the characteristics of the particular sewage sludge.

On the other hand, the characteristics of sewage sludge (in particular the wastewater sludge volume index, SVI), the conditions of flooding in the internal turbulence of the centrifuge rotor allow for an estimated assessment of the rate of sedimentation and an estimate of whether, at this rate, the particles of sewage sludge from a medium fluid position will be able to make their way to centrifuge, the external part of the rotor, where they will be discharged by means of a conveyor in the form of a dehydrated mass. Particles for which the life of the centrifuge will prove to be too short will inevitably be removed with the filtrate, thereby deteriorating the quality of dewatering. In this context, one of the tasks of the process is to mention the separation efficiency, the percentage of mass, which is discharged as the dehydrated mass and does not return to the WWTP system.

The long-term experience of centrifuge operation shows that in the absolute majority of cases, it is the third-way limitation of yield that appears to be limiting.

The first relationship, which gives an approximate insight into the parameters on which separation efficiency depends, is Stokes Law. The Stokes Law determines the rate of the sedimentation of spherical particles in the gravity (mass-centered) force field, depending on the various physical parameters:

$$v = \frac{2}{9}\frac{\left(\rho_p - \rho_f\right)}{\mu} gR^2,$$

where

v – sedimentation rate, m/s;

g – the strength or acceleration of the gravity field, m/s^2;

R – radius of spherical particle, m;

ρ_p – particle mass density, kg/m^3;

ρ_f – fluid density, kg/m^3;

μ – dynamic viscosity of liquid, kg/(m·s).

Water density at 20 °C, 998.2 kg/m³ (temperature dependent), dynamic viscosity $1{,}002 \times 10^{-3} \dfrac{kg}{m \times s}$ (depending on temperature (Figure 36)), the particle density is assumed to be 1040 kg/m³, the gravity field acceleration of approximately 3000 g or 30000 m/s². The approximate rate of sedimentation is calculated using the results achieved in the case of average particle size in sludge (Table 19), selecting the size of the various particles contained in sewage sludge.

Table 19

Example of Calculation of Sedimentation Rate

Name	*D*, μm (medium for particle type)	*V*, m/s
Cells	10	0.007
Wastewater sludge particles without flotation	100	0.694
Small flops	500	17.3
Big flops	1000	69.4

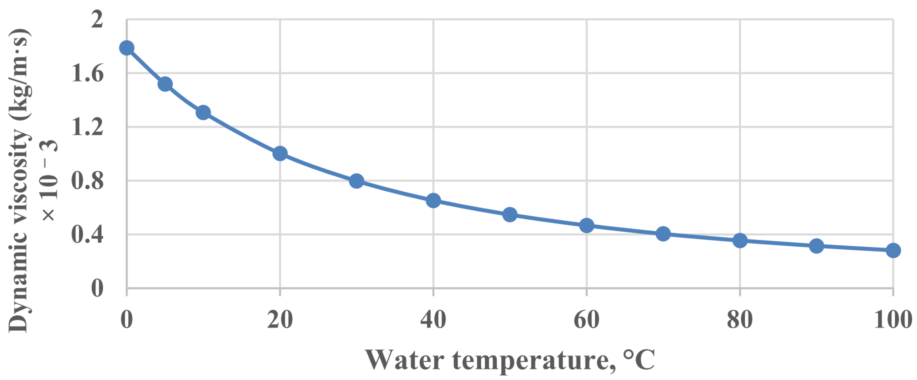

Figure 36. Dynamic viscosity of water depending on temperature

The rate of sedimentation calculated by Stokes Law is very high. Given that sewage sludge is located in a centrifuge for approximately 1 minute and the particles must be spaced to the periphery of the rotor approximately equal to 0.05 m, in theory, even very small particles should be easily detached. In practice, however, it does not happen. The Stokes Law applies quantitatively only to free sedimentation when particulate effects are not taken into account. The concentration of particles in sewage sludge is high and such an approximation cannot be justified. In addition, a large part of the separation process takes place in a zone with such high particle concentration that the environment is no longer considered to be Newtonian fluid, in which traditional viscous forces would operate.

Consequently, considerations based on the often reasoned Stokes Law, both centrifuge size and floculant type, should be treated with great caution.

However, the Stokes Law describes the main relationships qualitatively correctly: better separation is provided by higher rotational speed, higher particle density (hence less linked water), higher particle size (flocution, as well as possibly gentle transportation of sewage sludge through pipelines and trays), and lower water viscosity. Figure 36 shows the temperature dependency on the water viscosity.

It can be seen that even a slight rise in temperature from 10 °C (possibly the lowest temperature in winter) to 20 °C decreases the viscosity by 25 %. In practice, it has been demonstrated that where low-temperature heat is available as part of a technological process (biogas, drying/burning of sewage sludge, nearby industrial processes), it is appropriate to warm the wastewater sludge to approximately 60 °C before being centrifuged, thereby increasing the result of dewatering from 20 % to 26 %, without changing other conditions. In this case, however, it should be noted that increased temperatures set specific requirements for the floculant in question, since most "conventional" floculants are used to a temperature of up to 30–40 °C.

Main centrifuge regulation parameters

In general, the maximum permissible speed of a modern centrifuge rotor is selected for the design in question. This is determined by the centrifuge manufacturer, mainly on the basis of mechanical considerations.

Despite the frequency converter installed for the main drive, **the user should never change** the settings to exceed the speed prescribed by the manufacturer, as this may not only lead to damage of the equipment but also to serious accidents.

In the absolute majority of cases, there is also no reason for the user to decrease the speed, so it can be considered that the main (rotor) speed of the centrifuge is constant (usually 3000 – 4500 rpm/min), and the centrifuge is adjusted to the specific conditions by means of two parameters, the differential speed and the level of filtrate discharge.

Differential speed

The differential speed is the difference between the speeds of centrifuge rotor (*bowl*) and the conveyor rotation.

It is controlled by using a conveyor drive frequency converter. In modern systems, the frequency task is calculated at the required differential speed, while the actual differential speed control is carried out by automatic control systems while following the drive load, the torque value. Differential speed values are usually selected within 2–10 rpm/min, but in most cases the best separation result is obtained in the range of 4–8 rpm/min. A lower differential speed provides a higher dry matter content in the dehydrated mass. However, it should be noted that this increases the thickness of the dehydrated mass on the inside of the rotor. It has two kinds of consequences: firstly, the distance to the level of filtrate discharge is reduced, leading to a deterioration in the quality of the filtrate, and secondly, the load of the conveyor drive – torque – is increasing.

In practice, the differential speed value is the minimum value allowing for satisfactory quality of the filtrate, and the torque is within the permissible limits.

If the dry matter concentration of the wastewater sludge to be dehydrated is sufficiently high – 3–4 %, for example, the biogas process digested or previously concentrated sludge, a set torque regime may be used when the control system automatically adjusts the differential speed so that the torque is close to the maximum allowable but does not exceed it. In Latvia's practice, mixed sewage sludge is most frequently dehydrated directly from the recirculation contour with a dry matter content of around 1 %, so that the method cannot be used. The torque value is then well below the permissible peak.

Filtrate overflow level

The techniques for setting the overflow level of the filtrate may vary depending on the structure of the centrifuge: variable plates, sliding plates, tubes, etc. However, the aim of all these techniques is to set the level of overflow of the filtrate at the desired level (with the desired radius). In this way, "windows" are left for the discharge of the filtrate from the centrifuge rotor, usually four, for which the external edge of the radius determines the level of discharge of the fluid from the rotor or the thickness of the fluid layer in the rotor. Fluid in centrifuge cannot be closer than the set level (for reasons of accuracy, it should be noted that the flow of the overflow fluid, depending on the size of the flow (supply) and the width of the "windows", is of a defined thickness, so that the actual fluid level in the rotor is a few millimetres closer to the axis than mentioned in the setting details). The black line (Figure 35) represents the radius on which the nearest point is located to the axis of the dehydrated mass displacement aperture. If the liquid fraction is present at this level, it will be eliminated along with the dehydrated mass, which is not acceptable. This is a neutral level. This is usually indicated in the centrifuge manual. If the discharge of the filtrate is further adjusted from the axis, it is shown by a yellow line (Figure 35) and called the positive level (*Positive beach*). The liquid in the centrifuge is farther from the axle and cannot reach the dehydrated mass displacement port. Under certain conditions, such regulation also provides a drier dehydrated mass. However, such regulation has obvious shortcomings: the small radial distance between the dehydrated mass layer on the periphery of the rotor and the level of filtrate discharge leads to a higher content of suspended substances in the filtrate, in other words a "greased filtrate". Secondly, and this is very important, although it is often not taken into account: this will reduce the efficient volume of the rotor, the volume filled with liquids, reduce the lifetime of sewage sludge in the centrifuge and the quality of separation. Moreover, by increasing the radius of the filtrate's discharge by a certain size, the percentage of the effective volume may be greater than that resulting from a direct comparison of the radius, since it should be noted that part of the periphery is occupied by the slow transported dehydrated mass of the conveyor and the effective volume of the rotor is actually even smaller. The dehydrated mass space can be estimated approximately by taking into account the total amount of dry matter reported in the centrifuge in the time unit, the dry matter content of the dehydrated mass and the set differential rate.

The exact calculations are difficult to perform, but the main relationships – rotor geometry and mass flows – give a sufficient picture of the actual lifetime of sewage sludge in a centrifuge.

A red line (Figure 37) shows the fluid level closer to the rotor axis than the dehydrated mass displacement holes. It is called a *Negative beach*. Handling this regulation is only possible in centrifuges where a special baffle disc (*Baffle disc*) is created in the pipeline, shown with an arrow.

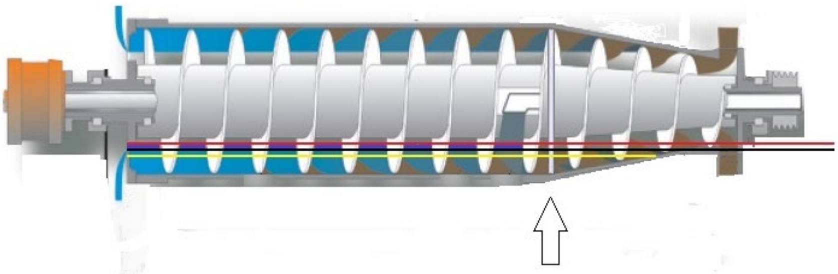

Figure 37. Overflow levels of filtrate

The baffle disc shall establish a local resistance to the flow of the dehydrated mass, and the effluent sludge sealing (*Sludge seal*) shall be established in this area. The sealing of sewage sludge is notionally airtight, which does not pass through the liquid fraction, but through it by the conveyor's transport force the mass of the dehydrated sewage sludge, which also provides for deeper dewatering of the mass. The structural features of the baffle disc, together with the size and characteristics of the sewage sludge flow, constitute a load inherent to the particular conditions for the conveyor drive, which is the largest component of torque readable in the interface of the control system. The maintenance of the sealing of sewage sludge in the time unit requires a specified quantity of dry matter. Therefore, for a centrifuge with such regulation, there is a minimum permitted sewage sludge feeder value for which, in the event of a lower value, the effluent sludge sealing is gradually degradable and the liquid fraction appears in the outlet of the dehydrated mass. In practice, there may be situations where low dry matter concentrations and high value of the sewage sludge volume index make it impossible to operate a centrifuge with a significantly negative level, because too much feeding flow leads to a short stay and low separation quality, but drastically reduced flow does not provide "material" for maintaining sewage sludge seals.

In such cases, the only solution is the setting of positive levels and longer working hours until the characteristics of sewage sludge in the biological treatment system have returned to normal.

Another problem at a negative level occurs in the case of short separation cycles where a centrifuge is washed after each cycle and the sewage sludge sealing is broken down. At the beginning of the next separation cycle, a significant amount of liquid enters the outlet of the dehydrated mass. In part, this problem is solved by the shuttles installed in the dehydrated mass outlet shaft for many centrifuges, which, when closed, direct the originally draining fluid to the filtrate outlet line. However, such a solution is not considered to be optimal because there is a significant amount of suspended substances entering the reusable basins and there is a risk of clogging the filtrate line.

In the current technology context, work with a negative level, organised as long as possible during separation cycles, should be considered as normal centrifuge operation.

Intake of sewage sludge into centrifuge

The intake of sewage sludge into a centrifuge is an important dewatering phase for which a special unit has been established for optimal disposal. In the sewage sludge intake scheme (Figure 38), the intake path of sewage sludge is shown by arrows. A stationary tube is entered along the centrifuge axis line through the hollow shaft of the conveyor approximately to the middle of the rotor (in the direction of the axle). A flow of floculant solution is supplied to the sewage sludge stream immediately prior to the inlet. Sewage sludge is released over the tube in about a second, and in this time the formation of flops cannot take place, it takes approximately 40 seconds. Such a scheme is chosen because, when flowing through the holes in the hollow conveyor shaft, the mass of sewage sludge receives an extremely strong impact which gives it rotation movement. If flocules had already been formed in this phase, they would have been shattered. The formation of flocules takes place by rotating sludge and floculant solution into a centrifuge.

It is important that the lifetime of sewage sludge in the centrifuge is not shorter than the 40 seconds needed to build flops.

Practice shows that overflow rates are observed relatively frequently. An indirect indicator for such a situation is a sample of the filtrate. If it is initially transparent, but within less than a minute it forms visible suspended particles, the flotation process is still ongoing. Such a situation is very undesirable because it not only does not provide a good separation result, but also leads to an irrational consumption of floculant.

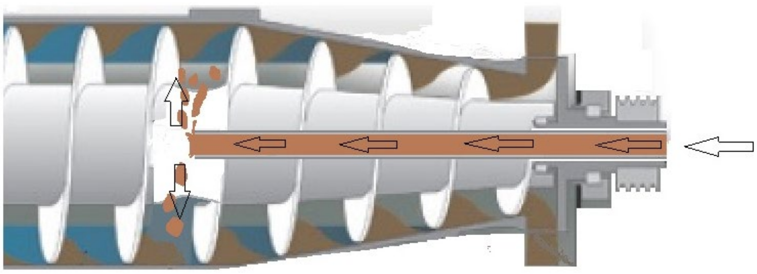

Figure 38. Effluent sludge intake scheme in centrifuge

Instead of the intake of sewage sludge, the “windows” of the pipeline's hollow shaft are reinforced by a technology that increases the resistance of that part to dilating, since the relatively abrasive mass of sewage sludge is forced to the surface by heavy force. The use of floculant is critical, as it also performs lubricant functions in this phase. When changing the conveyor bearings, the condition of this assembly must be checked.

If the centrifuge in question is equipped with interchangeable anti-wear inserts, they should be replaced in good time.

The majority of the energy needed to operate the centrifuge is consumed to cut the liquid mass to the centrifuge speed. The amount of water to be rotated is reduced by pre-notification of sewage sludge. Consequently, prior concentration of sewage sludge (without the use of floculant, this factor is more favourable in terms of the treatment of multi-stage sewage sludge), both by increasing the lifetime of sewage sludge in the centrifuge and by improving the quality of separation and by reducing energy consumption. The latter also requires that the energy consumption for dewatering the volume or mass of sewage sludge into a centrifuge is not correctly determined without looking at the entire technological chain.

Dewatering result

Two factors determine the quality of the dewatering process:

1) concentration of suspended substances in the filtrate;
2) dry matter content in dehydrated mass.

The concentration of suspended substances in the filtrate is also expressed as a *recovery rate*.

The rate of return determines the percentage of dry matter, which, after separation, enters the dehydrated mass rather than the filtrate.

As a general rule, the amount of suspended substances in the filtrate is less than 300 mg/l, or the return rate is 97–98 %.

In case of good optimization of all factors (centrifuge quality, appropriate performance parameters, optimal floculant selection), results such as suspended substances content 20–40 mg/l and a return rate above 99 % are also possible.

The dry matter content in the dehydrated mass depends to a large extent on the type of sewage sludge. Primary sewage sludge is effectively dehydrated, but in Latvia it is virtually nowhere, because in the only WWTP with primary guideliners (Riga) mechanically untreated primary sewage sludge is passed into the biogas plant along with concentrated excess biological sludge. After processing in biogas plants, digestat can be dewatered sufficiently effectively with a dry matter content of up to 32 %.

In Latvia, mixed sewage sludge is dewatered in most WWTPs – there are no primary guideliners, and fine sand and other more easily sinking deposits come into total mass with biologically active sludge.

In this case, the dry matter content of 20 % in dehydrated mass has been considered as a good result of dewatering.

However, depending on the composition of the effluent, the wastewater sludge volume index, the use of floculant, the quality of the equipment and process optimisation, the dry matter content in the dehydrated mass is within 16–23 %. Not necessarily a better dewatering result can only be achieved by optimizing the operation of centrifuge and related equipment. If a large amount of wastewater of industrial origin with insufficient or completely non-existent pretreatment, such as high fat content, the 20 % dry matter content, traditionally considered to be of good dewatering results, may prove to be unattainable.

Of the wastewater sludge dewatering technologies used in Latvia it the centrifuges that provide the highest dry matter content in the dehydrated mass.

Given the need to reduce the total amount of sewage sludge to be disposed of, this is an important consideration.

Operation and maintenance

Centrifuges can be operated in continuous mode 24/7. It is recommended that a small buffer with a mixing tank be used to achieve a stable position. This is particularly beneficial for large WWTPs. In an average WWTP dewatering is done in one or two shifts (eight or 16 hours five days a week). A direct supply to the dewatering facility may also be possible.

The centrifuge must be cleaned by a washing for 5–15 minutes before stopping when the end of the effluent sludge and floculant solution is released.

It should be noted that the centrifuge is not airtight and that the flushing water does not flow into the storage and/or the room of the dehydrated sewage sludge should be rotated during the flush. The flushing efficiency is slightly increased by a high differential rate set at its time. It should be noted that during the flush, the effluent sludge shutter around the baffle disc is likely to be dissolved, and if a negative fluid level is set for the centrifuge, the flushing water will also begin to run through the openings of the dehydrated mass. Accordingly, it will take some time (usually several minutes) when the next separation cycle starts, but this depends on the design of the centrifuge, the rate of the sewage sludge supply, dry matter concentration and flotation. This is the negative aspect of flushing. From this point of view, maximum working cycles without stopping sewage sludge supply are desirable. If the sludge is not too sticky and it is practical to ascertain whether the dehydrated pieces adhering to the conveyor do not cause increased vibration during re-starting, the centrifuge may not be flushed at any time. In some cases, in the centrifuge control system, the manufacturer shall include a special flushing programme, including breaking water supply, variable rotation speed and even reversing.

Bearing lubrication

The centrifuge has basic and conveyor bearings. The underlying bearings are exposed to high rotational speed and significant vibration.

As a result of the specificity of centrifuge operation, the vibration intensity of up to 25 mm/s shall be considered acceptable in individual cases.

The diameter of the bearing and the linear speed of the balls or rollers, respectively, is also relatively high. In addition, water or even small amounts of sewage sludge cannot be completely excluded. All of them should be particularly responsible for bearing lubrication.

Only consistent lubricant types recommended by the manufacturer must be used.

The basic bearing lubrication is carried out when the centrifuge is operating, using special lubrication connection areas. The lubrication interval is normally between 100 and 300 working hours. It depends on the type of lubricant used in individual manufacturers' plants, while the lubricants produced by the manufacturers allow longer intervals between lubricants.

When lubricating the underlying bearings, the exact number of movements of the lubricating pig determined by the manufacturer must be carried out.

Too much lubricant leads to an unwanted increase in the bearing temperature. Lubricant channels are usually designed to allow visual monitoring of the pressure of the old lubricant from the bearing room. The conveyor bearings are integrated between the centrifuge rotor and the conveyor, so their rotation speed is small, equal to the differential speed, so the dynamic load is significantly lower than the base bearings. It should be noted that, unlike the underlying bearings, at least one conveyor bed also transfers a significant axial load. In addition, the conveyor bearings are closer to the sludge and are better protected against their negative effects. Overall, however, the load of the conveyor bearings is much lower and their lubrication intervals are significantly longer, usually 2000–4000 working hours. Most centrifuges are designed so that the conveyor bearing lubrication channels cross only the rotor parts, so lubrication should be done by stopping the centrifuge. In the same way as the underlying bearings, a certain number of strokes of the lubrication piston must be performed. For individual, usually small-size centrifuges, bearing lubrication channels are designed so that the basic and conveyor bearings are lubricated simultaneously.

Bearing replacement

The main regular centrifuge maintenance is basic bearing replacement. As a general rule, there are no strict manufacturer requirements for replacement intervals.

The wear of the bearings is indicated by increased vibrations and/or changes in sound during operation.

The basic bearing replacement intervals are difficult to express in working hours because the worked time is only one aspect of wear. The lifetime of the bearing is significantly reduced by short working cycles with repeated warming/cooling, increased vibration due to various operating factors, as well as by the presence of multiple centrifuges on the same base, some of which are operating and some not. This situation leads to a significant additional deterioration of the standing centrifuge bearings.

The classic "one works, one in reserve" scheme is very undesirable in the case of centrifuges.

In general, basic bearings should normally be replaced every 1–3 years. All seals recommended by the manufacturer must also be modified at the same time as the bearings. The operation of basic bearings is extremely undesirable for as long as they leave the ranks, as this could lead to a much larger damage to the equipment.

Switching conveyor bearings

The conveyor bearings should normally be replaced after each replacement of three or four basic bearings. During this replacement, the protective coating of the pipeline winds and the condition of the anti-dilating inserts at the inlet of the sewage sludge must be checked, as these zones are not visible in the day. For individual centrifuges, however, special cork-screwing drills on the rotor wall can be measured along the length of the conveyor to the rotor wall, followed by dilution.

If the strands of the pipeline are visibly threadbare, exceeding several millimetres (the dilutions usually make the most rapid progress in the transition zone from the cylindrical part to the conical), the only solution is – the manufacturer supplies a new or commercially refurbished conveyor.

The dilutions of pipeline strands and sewage sludge intake inserts are difficult to predict. This is influenced by the amount of sand in sewage sludge. In some cases, these parts do not need to be replaced throughout the life of the centrifuge.

Control of dry discharge insert position

Dry mass discharge ports have been created at the conical end of the centrifuge rotor, usually – eight. The centrifuge conveyor shall push the dehydrated mass to the ports (openings) where it is released under the centrifugal force. The mass is abrasive and has been operated by large dynamic forces, particularly as a result of the Coriolis acceleration. Even high-quality stainless steel parts dilate very rapidly under these conditions, so anti-dilutions are inserted into the ports. They may be made of some particularly solid material, such as tungsten carbide, but may also be stacked from an outer shell of steel and a ceramic inner shell.

The condition of the inserts must be followed regularly and in no case shall they be allowed to dilate to such a degree that the process of dilating the rotor itself begins.

The inserts are interchangeable and can be ordered by the manufacturer. However, carefully following the insert-wear process, it is possible for most centrifuges to significantly extend the working life of the inserts. As a result of the dynamic forces of discharge, the penetration of the inserts is significantly uneven. If dilutions are observed in good time, which have not yet reached the thickness of the entire insert at any point, the insert attachment may be released and turned by 120 degrees, exposing another, "fresh", circumferential part to the dilutions. In this way, three operating periods of the insert are obtained, providing a more rational use of the expensive anti-wear material as a whole.

In any case, the operator of the equipment must comply with all requirements and carry out the activities specified by the manufacturer of the equipment concerned.

Primary sludge requires more torque and has higher material erosion potential than excess sludge.

Interchangeable anti-wear sleeves on the end of the screw and solid metal coatings in areas exposed to heavy wear reduce maintenance costs.

Costs

The cost of capital depends on capacity and typically ranges from EUR 100 000 to EUR 250 000. The operating time of the installation is normally 15–20 years, but if the preventive maintenance of bearings and other dilating parts of the equipment is not performed properly, this time may be reduced to 10–15 years.

Electricity consumption by dewatering sewage sludge with centrifuges is higher than by other methods of dewatering sewage sludge.

If we assume that the electricity price for water holdings is approximately EUR 0.15/kWh, the electricity costs for dewatering wastewater sludge with a centrifuge in the case of dry matter shall be approximately **EUR 13.50–30.00 kWh/t dry matter**. It should be noted that smaller centrifuges work with a slightly lower efficiency, so electricity consumption per tonne of dry matter will also be higher than with high-capacity centrifuges.

When treating municipal sewage sludge, **polymers are required for the centrifuge** to accelerate and ensure the separation of water from solids. The type and characteristics of polymers must be checked for each type of sewage sludge and for each dewatering plant. Centrifuges do not consume too many polymers and are able to process volumes above the nominal volume to be processed and contain a higher dose of polymers, although in this case the dry matter content in the dehydrated mass may decrease slightly.

The consumption of the polymer by mingling sewage sludge with centrifuges, compared to the screwed presses and filtering presses, is the smallest.

This is due to the fact that centrifuges develop a very high acceleration, which contributes to the removal of even weaker-stabilised wastewater sludge flakes from the water. The consumption of the polymer depends on many factors, such as the consistency of sewage sludge, the degree of fermentation, the relationship between primary and superfluous sewage sludge and the content of organic matter in sewage sludge, and the choice of the preferred polymer, as there is less consumption with a better suitable polymer.

The consumption of the polymer is between 3.7 and 12 kg per tonne of dry matter. Assuming a polymer price of EUR 3.00/kg and a polymer consumption of between 3.7 and 12 kg per 1 tonne dry matter, it should be concluded that the cost of the polymer for dissolving sewage sludge with centrifuges is approximately **EUR 11.10–36.00 per tonne of dry matter**. When dewatering sewage sludge with centrifuges, the polymer costs approximately equal to electricity costs (Table 20).

Table 20

Total Operating Costs of Centrifuges

Electricity costs, EUR/t dry matter	Polymer costs, EUR/t dry matter	Total costs, EUR/t dry matter
10.80–24.00	11.10–36.00	21.90–60.00

4.3.3.6. Screws

The screw press is a modern wastewater sludge dewatering plant, which provides a satisfactory content of the dry matter of the dehydrated mass and a good quality of the filtrate.

These parameters should be assessed on the same basis as the decanter centrifuge and ribbon presses, including the amount of the mass to be disposed of, the dry matter return rate and the resources to be consumed as the criteria for selection.

Compared to decanter centrifuge, the bolt press provides a slightly smaller dry-matter content in the dehydrated mass.

If the other conditions are similar, the difference is valued at approximately 18 % of dry matter with a screwed press and 22 % dry matter with a centrifuge. Compared to the ribbon press, the results are similar. However, account should be taken of the dependency expressed by the result of the use of the screw press on the rate of sewage sludge and the quality of flotation. An optimal combination of sewage sludge properties and floculant selection can also be achieved with the screw press by achieving a dewatering result exceeding 20 % of dry matter, but if floculation is not optimal, a corresponding high result cannot be achieved only by adjusting the performance of the screw press.

Compared to a centrifuge, the bolt press consumes less electricity.

It is difficult to specify precisely this difference because the energy consumed by the centrifuge depends to a large extent on the characteristics of sewage sludge, particularly the concentration of dry matter in it.

The bolt press consumes much more flushing water compared with a centrifuge, but roughly similar or smaller amount of water compared with a ribbon press.

Compared to the ribbon press, the bolt press has a number of advantages – a better chance of controlling the quality of the filtrate, a simpler kinematic scheme, because both the premeditating and dewatering process are combined into a joint-drive, more compact design, occupying less room.

Fitness

The bolt press is considered to be an appropriate wastewater sludge dewatering technology for WWTPs with population equivalent of up to 50 000 PE, where a slightly higher amount of dehydrated mass does not play a decisive role. However, this does not apply to the WWTP which involves the successive drying and burning of thermal sewage sludge, since the lower dry matter content will require a higher amount of additional energy to be delivered.

Compared to a centrifuge, the bolt press has fewer quickly dwindling parts and simpler maintenance.

Compared to the ribbon press, it may be considered as an advantage that there are no relatively expensive parts and belts (or multiple belts) exposed to wear.

Advantages and disadvantages

Advantages	Disadvantages
Consumes far less electricity than centrifuge	Requires qualified workforce
No fast rotating components	It is necessary to select the polymer brand carefully and to prepare the work solution qualitatively
Less quickly descending parts (compared to centrifuge)	Lower dry matter than centrifuge
Simple maintenance	High polymer consumption
Not expensive and wear-prone parts – belts (compared to belt press)	Consumes more flushing water (compared to centrifuge)

Better control of the quality of the filtrate (compared to the belt press)	
Compact design, occupies less space	

Technology

Bolt press is designed for a continuous process of dewatering sewage sludge. Dewatering is carried out by exerting pressure on the surface of the filter element. The bolt continuously transports sewage sludge through the press – from intake to discharge. Sewage sludge is compressed and drained through the press by rotation, while the released water is filtered through a sieve.

Sewage sludge is exposed to the press by the positive action, usually by the eccentric bolt pump. A connection to the floculant solution is established immediately behind the pump. A mixing assembly is placed behind the connection of the floculant solution, usually designed as a weight-adjustable valve with a narrow gap opening. In this way, the turbulence required for an effective mixing process is ensured. After mixing of the effluent sludge and floculant solution, a specified period of flooding is needed in order to develop persistent effluent sludge structures – flocules. For this purpose, a flotation reactor with an appropriate capacity has been established which, in the case of the planned wastewater sludge supply yield, provides the required flooding time, usually not less than 40 seconds.

Build-up

The principle of the operation of the screw press is based on filtration through the sieve, so it is very important that the wastewater sludge flops are as robust as possible. The size of flocules has a secondary meaning.

The design of the screw press may vary (Figures 39 and 40), but the main operating principle for both structures is the same. The position of the bolt drive, the operation of the flushing system and the degree of automation are different. The design of the older press has a fixed flushing nozzle collector, the latest design has a moving flushing nozzle collector basket.

The main knots of the screw press unit are a conical bolt shaft and a cylindrical sieve consisting of three processing zones: intake area, three-part thickening and dewatering areas and press areas with a pneumatic-powered back pressure cone. The screws must be supplied in the press with a sufficiently stable flow of sewage sludge.

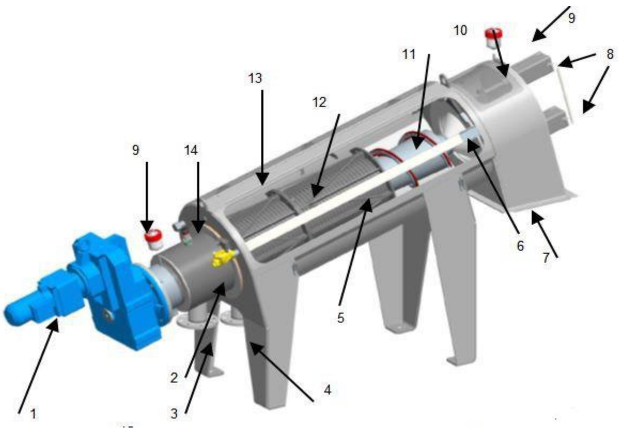

Figure 39. Screw press of older design[26]

1 – Bolt drive; 2 – flushing water connection with solenoid valve; 3 – sludge intake connection; 4 – filtrate discharge compound; 5 – flushing nozzle manifold/flushing nozzle; 6 – back pressure cone; 7 – sludge discharge chamber; 8 – pneumatic cylinder with compressed air attachment; 9 – bolt bearing lubrication nipple; 10 – sludge discharge inspection cover; 11 – bolt; 12 – cylindrical sieve; 13 – sieve zone inspection cover; 14 – sludge intake chamber pressure switch.

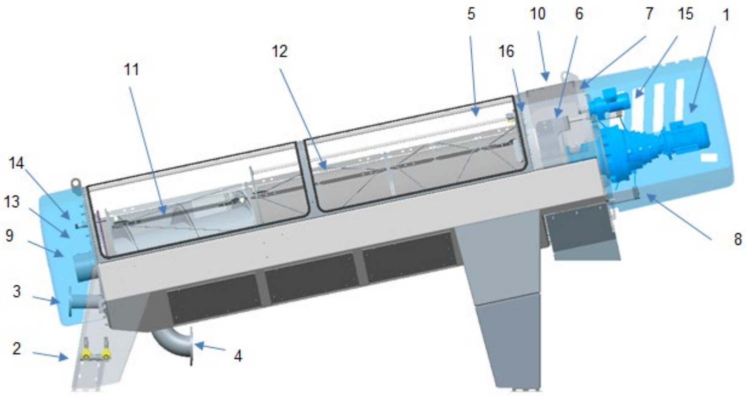

Figure 40. Screw press of latest design [27]

1 – Bolt drive; 2 – flushing water connection with solenoid valve; 3 – sludge intake connection; 4 – filtrate discharge compound; 5 – flushing nozzle manifold/flushing nozzle; 6 – back pressure cone; 7 – sludge discharge chamber; 8 – pneumatic cylinder with compressed air attachment; 9 – bolt bearing lubrication nipple; 10 – sludge discharge inspection cover; 11 – bolt; 12 – cylindrical sieve; 13 – sieve zone inspection cover; 14 – sludge intake chamber pressure switch; 15 – flushing nozzle basket drive; 16 – flushing nozzle amendment.

In the first section of the sieve, the free water contained in sewage sludge is quickly separated through the large surface of the sieve by the flow generated by the feeder pump and under a low pressure. The pressure sensor in the intake protects the equipment from excessively high primary pressure and consequently excessive filtrate contamination.

[26] www.huber.de

[27] www.huber.de

In the second section of the sieve, due to the conical shape of the shaft of the bolt, the volume of material between the twists of the bolt is reduced and the sewage sludge is pressed against the inner surface of the sieve, thereby dewatering and gradually reducing the thickness of the dehydrated mass layer. In this section of the sieve, the sieve eyes are much smaller.

In the third section of the sieve, the compressed air-operated back pressure cone expresses the remaining mechanically detachable water. For the purposes of this section, the clearance layer is the thinnest. Taking into account the type and consistency of wastewater sludge flops, the pressure applied to the sludge may be modified as necessary.

The transporting bolt presses the dehydrated sewage sludge along the back pressure cone in the discharge chamber. The retention time of sewage sludge in the press of the screws, and thus the filtering time can be adjusted according to individual requirements by adjusting the speed of rotation of the bolt shaft.

Skateboards fitted to the strands shall ensure the continuous automatic cleaning of the sieve from the inside. Sieve flush with specified time intervals from outside is provided with a flushing nozzle collector. This function works differently for different press structures.

For older press systems, the flushing nozzle collector is stationary but the sieve is a rotating element. In the working mode, when the sewage sludge is fed, the screws are operating in the same direction but the sieve is fixed. When flushing starts, the effluent sludge feeder is interrupted, the bolt shaft rotates in the opposite direction. The trigger mechanism releases the sieve and rotates with the screw. In this way, a full circle sieve rotation is carried out during flushing, ensuring a smooth flush from all sides. Then the working mode resumes when the bolt shaft rotates towards the transport of sewage sludge, the trigger mechanism restores the sieve, the sewage sludge feeding resumes and the dewatering process continues.

For newer press structures, the dewatering process is not interrupted during flushing. In this case, a moving basket with a number of nozzle collectors is created which, when the basket moves within a particular sector, completely rinse the surface of the sieve.

Main aspects of the bolt press dewatering process

Speed control of the press bolt shaft behind the place of application of the primary pressure (pressure intake area).

The drive of the bolt equipped with the frequency converter shall ensure the continuous transport of the mixture of sewage sludge and floculant solution from the intake area through the entire press volume of the screw.

If the characteristics of sewage sludge and/or flotation do not change, the speed of the screw rotation also does not change, it is approximately 1 rpm/min.

If the characteristics of sewage sludge and/or flooding vary significantly, it is possible to adapt to them by using the speed control of the screw rotation behind the place of application of the primary pressure or pressure in the intake area. It should be noted that in this zone sewage sludge contains a large amount of water, the viscous forces that link parts of mass are small. The sieve eyes are relatively large, and large amounts of water must be passed through them. As a result of these factors, the sludge on the surface of the sieve must not be subjected to excessive pressure, so that it does not lead to the destruction of flocules and the displacement of large quantities of dry matter particles through the sieve together with the filtrate. In fact, the pressure of sewage sludge on the surface of the filter in this zone is caused by the sewage sludge feeder pump, while the bolt transports the mass of sewage sludge to the next zones, thereby freeing the room for the intake of new sewage sludge and lowering the pressure. Therefore, in automatic control mode, a linear relationship is set between the pressure in the intake area and the speed of the screw rotation. The optimum primary pressure value shall be determined visually by the quality of the filtrate in this zone. Usually, the pressure value is small – 200–300 mbar. Following the diffusion mass of the liquid, the filtration process in this area can be compared with that of the rotary sieve compactor.

If the maximum speed of rotation of the bolt is reached but the primary pressure is too high and the filtrate shows a significant amount of particles of sewage sludge, the feeding of sewage sludge to the press should be reduced.

Modern control systems include a function that automatically interrupts the sewage sludge supply, reaching a certain pressure limit. When the pressure value decreases to a set supply recovery level, the feed is resumed. This function is practicable in the use of the press in the torque control mode, since it is possible at the same time to prioritise the maximum dry matter content in the dehydrated mass without deteriorating the quality of the filtrate in the containing area.

Bolt shaft speed control behind torque application point

In this control mode, the speed of rotation of the bolt is directly proportional to the torque on the shaft displayed by the drive frequency converter. The selection of this regime means that the process in the dewatering zone plays a priority in the management process. The slower the operation of the bolt, the longer the wastewater sludge stays in the press, the pressure on the surface of the filter in the dewatering zone increases accordingly. This press action is desirable, as it provides a maximum dry matter content in the dehydrated mass. However, it is limited to both the risk of reaching the screw recovery load limit and (more often) the extortion of large amounts of sewage sludge through a filter in the dewatering zone, i.e., "sewage sludge worms". As with the primary pressure control mode, the torque control mode may be supplemented with the stop/resume function of the effluent sludge supply.

Back pressure cone action

The back pressure cone integrated into the wastewater sludge discharge unit of the installation shall act as a counterreaction to the dehydrated sewage sludge flowing in the direction of the axle. This component, in shape, is a bevelled ring cone which can be printed by pneumatic drive at a variable depth within the discharge gap of the ring-type sewage sludge. Depending on the depth of the printing changes the resistance to the flow of dehydrated sewage sludge in the gap and the pressure on the surface of the filter in the dewatering zone, as appropriate.

In the normal dewatering process, the position of the back pressure cone is determined by the dynamic balance between the draining mass and the pressure of the compressed air in the cone-driven pneumosystem.

The pressure to be set in the pneumosystem shall be selected according to the desired pressure on the surface of the filter. It should be noted that the outer diameter of the back pressure cone is less than the external diameter of the discharge gap for sewage sludge, and therefore, even in the case of high pressure of pneumosystem, the discharge gap of sewage sludge will not be completely closed. If the reversible sewage sludge does not produce an appropriate axial force, the cone will be pushed into the slot until the stop, and the maximum available value will be maintained for the resistance of the sewage sludge flow.

The pressure of pneumosystem is most frequently adjusted within a few bars.

It should be noted that this value depends on the diameter of pneumocylindrical and the cross-sectional area ratio of the effluent sludge output gap, and therefore the pressure in pneumosystem **IS NOT** equivalent to the dewatering pressure of sewage sludge.

Compatibility between sewage sludge and floculant plays a major role in the operation of the discharge unit. Even if the chosen floculant provides a good water separation, it is not enough for the success of the press. An incorrectly selected or overdose floculant often leads to the adhesion of the dewatered waste water sludge mass to the twists of the screw, which leads to a significant portion of the press cross-section area being blocked, and the remainder of the free part in the form of a "tunnel" causes a stream of sewage sludge with a much smaller dry matter content. This phenomenon can be identified by observing the discharge of the dehydrated mass along the back pressure cone. If the press is optimal, a steady mass "carpet" forms throughout the cone's perimeter. If there is no mass flow in any sector, while another shows a rapid release of reduced viscosity mass, it can be reliably concluded that the flotation parameters should be reviewed.

Operation of the flushing system

Presses of older design are washed by breaking the sewage sludge feeder, reversing the bolt drive, releasing the sieve from the cap fixation and rotating it. The flushing nozzles are fixed on a stationary collector, but the flushing system is limited to opening and closing the solenoid valve. The sequence of all operations – interruption of sewage sludge supply, reversal of recovery, opening and closing of solenoid, reversing of recovery, recovery of sewage sludge supply – shall be included in the automatic management programme.

For newer press structures, dewatering of sewage sludge and accordingly the feeding of sewage sludge during flushing is not interrupted. Using a separate engine drive, a sieve-covering basket, on which several nozzle collectors have been assembled, is rotated at a specified angle in both directions. The flushing flow is divided into several sections allowing for the programming of different flushing modes that can be executed sequentially depending on the speed of clogging the sieve. Such a design enables a more rational use of press working time, does not disrupt the stationary flooding process, saves flushing water, and minimises the disintegration of individual press parts.

Dewatering result

In the case of proper operation and a medium-sized wastewater sludge volume index, screws in the dehydrated sewage sludge shall be capable of providing a dry matter content of up to

20 %. Despite the theoretically high achievable dry matter content in dehydrated sewage sludge, the majority of the screws dehydrated sewage sludge is only **up to 10–14 % dry matter**, which is a weak indicator. If the average dry matter content of the effluent sludge dehydrated by filtering agents is 14.65 %, then for the screws press it shall be 13.48 %.

Operation and maintenance

Servicing the bolt press is relatively simple. The manufacturer's instructions must be strictly followed, particularly as regards the operation of the various safety systems, lubrication. The modern screw press control system shall be designed to protect from all types of congestion and, if necessary, signal damage to any sensor or other source of signal.

Not only should the functions of the automatic control system be followed, but also the quality and pressure of the flushing water; make sure that all nozzles are operating during the flushing cycle and that all parts of the sieve are appropriately flushed or that sewage sludge does not become contagious.

The dilating parts are interchangeable brushes on the twists of the bolt; when longer operating the equipment, it is also the surface of the back pressure cone. But for the older press structures, the surface of the flanch of the sieve tip along which rotation takes place during the flush.

Maintenance of drives, actuators and sensors must be performed in accordance with the manufacturer's instructions and good engineering practices.

Costs

If we assume that the electricity price for municipal utilities is approximately EUR 0.15/kWh, if there is 4–12 kWh/tonne dry matter, the electricity costs for dewatering sewage sludge with the screw presses are approximately **EUR 0.60–1.80/tonne dry matter**.

Dewatering excess sewage sludge with the screwing presses requires approximately the same polymer consumption as dewatering with filtering presses but larger than with decanter centrifuge. If the objective is to reach the maximum dry matter content in dehydrated sewage sludge, the normal consumption of the polymer when working with the screw presses shall be 8–12 kg of polymer per 1 t of wastewater sludge dry matter. If a lower dry matter content is allowed in dehydrated sewage sludge, the consumption of the polymer shall be reduced accordingly.

Assuming a polymer price of EUR 3.00/kg, in the case of a polymer consumption of 5–12 kg/tonne dry matter, the cost of the polymer by dehydrating sewage sludge with a screw press is approximately **EUR 15–36/t dry matter**. The total operating costs in the case of typical screws in the case of electricity consumption are summarised in Table 21.

Table 21

Total Cost of Dewatering Sewage Sludge with Screw Presses

Electricity costs, EUR/t dry matter	Polymer costs, EUR/t dry matter	Total costs, EUR/t dry matter
0.48–1.44	15.00–36.00	15.48–37.44

The costs of the polymer are significantly (at least ten times) higher than electricity costs when dehydrating excess active sewage sludge with screw presses. Consequently, the costs of the polymer represent approximately 95 % of the total direct costs of dewatering sewage sludge.

4.3.3.7. Disc presses

Disc press is a type of screw press for which the filter sieve has been replaced by a disc structure. The structure of many, alternately stationary and moving ring discs covering the sewage sludge transport bolt forms a filter element. The eye analogue of the filter sieve forms like a gap between the stationary and the movable disc.

Fitness

Like the screw presses, disc presses are suitable for dewatering the amount of sewage sludge produced to not too large WWTPs, with a population equivalent of up to 50 000 PE and no maximum level of dry matter.

Advantages and disadvantages

Advantages	Disadvantages
Simple and easy to monitor	Require qualified workforce
Relatively low energy and water consumption	It is necessary to carefully select the polymer brand and to prepare the work solution qualitatively
Less quickly descending parts (compared to centrifuge)	Lower dry matter content than with centrifuges
Simple maintenance	High polymer consumption
Compact design, takes less space	Consumes more flushing water (compared to centrifuge)

In the current situation in Latvia, disc presses could be installed in many WWTPs without any mechanical wastewater sludge dewatering equipment, as well as replacing of the physically worn belt filter presses. The disc press, at least at the current level of technological development, cannot replace the large WWTPs in any way, since there are no reliable data on the frequency of disc replacement and the cost of operation, respectively, in Latvia.

Technology

Sewage sludge from the sewage sludge tank is transferred to the upper tank (Figure 41), which is notionally divided by a partial wall into two sections – dosing and flogging. The pump sucks the sewage sludge into a dosing section equipped with an overflow pipe to be adjusted at a specified height. The pump yield is guaranteed to exceed the preferred amount of supply to the press. The corresponding overflow height provides constant hydrostatic pressure at the inlet of the working cylinders of the press. From the dosing section, sewage sludge is transferred into the flooding section, mixed with a floculant solution prepared in a pre-existing installation (as with all dewatering technologies) and passed through a flexible tube into the service cylinders of the press. It should be noted that the actual flow of sewage sludge through the working cylinder depends on the parameters of the dewatering process, which may be time variable regardless of the constant hydrostatic pressure in the dosing section. This is considered to be a lack of press on the disks, particularly because the flow of floculant solution is handled by an adjustable yield pump, but without feedback to the variable sewage sludge flow. Therefore, the addition of the active substance of floculant corresponding to the dry matter content and the flow of sewage sludge is likely to be relatively short-lived. Adding a floculant solution to a small-size flotation section just before the intake into the working cylinders of the press also does not provide a homogenous floculation with a steady passing time throughout the volume of the flooding area. The design of the working cylinder also prevents high dewatering pressure.

The dry matter content of the dehydrated mass shall normally not exceed 15 %.

A separate sewage sludge tank allows convenient dosing of a coagant, such as iron chloride, when needed. Such a two-reagent application scheme may improve the dry matter content in the dehydrated mass, but its targeting depends on the particular characteristics of sewage sludge and should be examined on a case-by-case basis.

By adapting constructively the length of the sections of the work cylinders, a disc press adapted to the dewatering of various dry matter sludge can be targeted. Producers typically present a range of 0.3–2 % of dry matter. When dimensioning the disc press for a particular yield, it should be noted that, compared to the sieve filter bolt press, the pressure in the area is several times lower, so the filtration intensity will also be lower.

Figure 41. Compact installation of the disc press[28]

Build-up

The disc press typically has more than one working cylinder – a set of discs with a transport bolt (Figure 42) enables you to perform press maintenance on parts without breaking the dewatering process.

[28] https://www.tsurumi.eu/

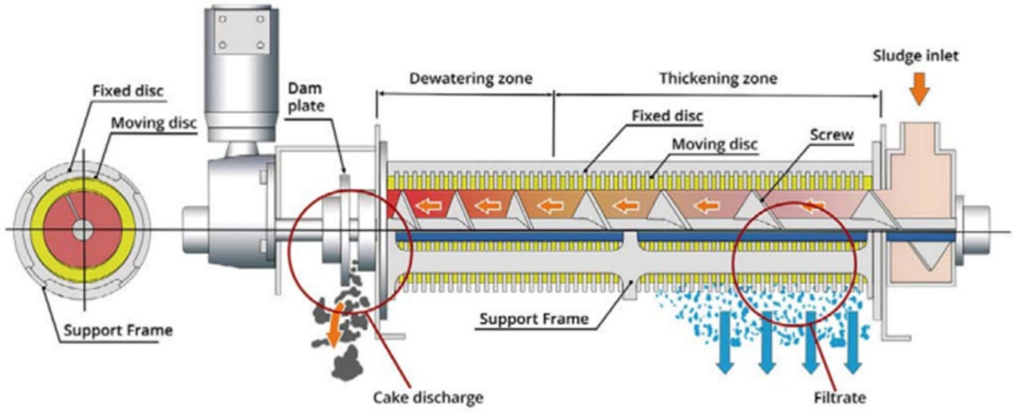

Figure 42. Disc press operation diagram[29]

The main feature of the operation of the disc press is the formation of the filter surface using appropriate movement.

The transport bolt is covered by a set of discs in which stationary and moving discs are installed alternately. The geometry of the disc assembly and the bolt is such that when the bolt rotates, it touches the moving discs and forces them to make complane movements with a few millimetre amplitude relative to the stationary drives. This ensures the cleaning of the filter gaps. Unlike with the screw press, there is no need for intense high pressure flushing, only mild water blasts are needed. Previously flooded sewage sludge flows into the working cylinder. The front part of the cylinder is subjected to gravity contamination of sewage sludge – filtering the largest portion of water between the disks. In the back of the cylinder, where less water is left in the sewage sludge, the screw turns step is smaller and dewatering is carried out at the pressure of the bolt.

A stop plate is installed in the cylinder outlet, adjustable away from the last disc, providing the required back pressure. The water nozzle mounted on the collector shall provide a small flow of water sufficient to rinse the few particles of sewage sludge pressed between the disks. The speed of the screw rotation is very low – 1–2 rpm. Such a regime provides a noticeable energy economy.

[29] https://www.tsurumi.eu/

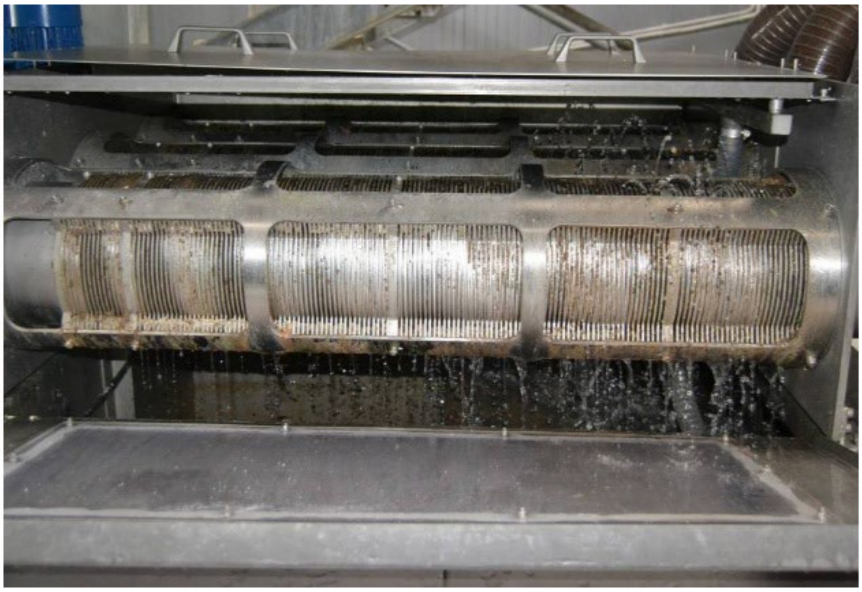

Figure 43. Disk press work area during dewatering process[30]

The disc material may vary (Figure 43) but it most frequently uses a special brand-resistant steel. Kit discs are parts of the equipment that are regularly changed, so their wear should be carefully followed. In each case, the frequency of disc replacement depends on the amount of disc material and sand in sewage sludge.

Compared to the sieve filter bolt press, the disc press control system is much simpler – there is no pressure and torque control, there are no air-controlled back pressure devices in place of dehydrated mass release.

Therefore, the disc press installation is designed according to a simple control scheme, and its auxiliary equipment is in most cases considered to be an integral part of the machine (i.e. a traditional feeding of sewage sludge with a pump would not allow the use of a press technological scheme).

4.3.3.8. Belt presses

As the name itself suggests, the action of the belt filters is based on filtering. After the sewage sludge has responded with the polymer, a special distribution unit shall apply the mass of sewage sludge to a moving filter belt. The water flows through the belt, while special coils press the mass of sewage sludge to facilitate dewatering.

Fitness

Belt presses are often used for the dewatering of fermented sewage sludge, but the equipment can also be used when dewatering wastewater sludge that has not been fermented. In the past, these machines have been widely used for small and medium WWTPs, but they are now increasingly replaced by centrifuges, given their compact and closed build-ups. There are also

[30]www.ekoton.com

belt presses produced to be installed in trucks, which can be used by a number of small WWTPs, ensuring that costs are distributed between water holdings.

In Latvia, the ribbon presses are used mostly for the dewatering of wastewater sludge from small towns.

Advantages and disadvantages

Advantages	Disadvantages
Price lower than that of centrifuge	Dry matter content – 12–16 %
Low electricity consumption	Flushing requires significant consumption of clean water
No fast-rotating components	Relatively large installations and takes up a lot of space
There are not many descending details that should be changed regularly	
Simple maintenance	
Not requiring expensive and complicated repairs	

Technology

There are a number of types of belt press structures that basically differ in the number of belts and rolls. There are simple structural belt presses (Figure 44) that are cheap and simple in exploitation.

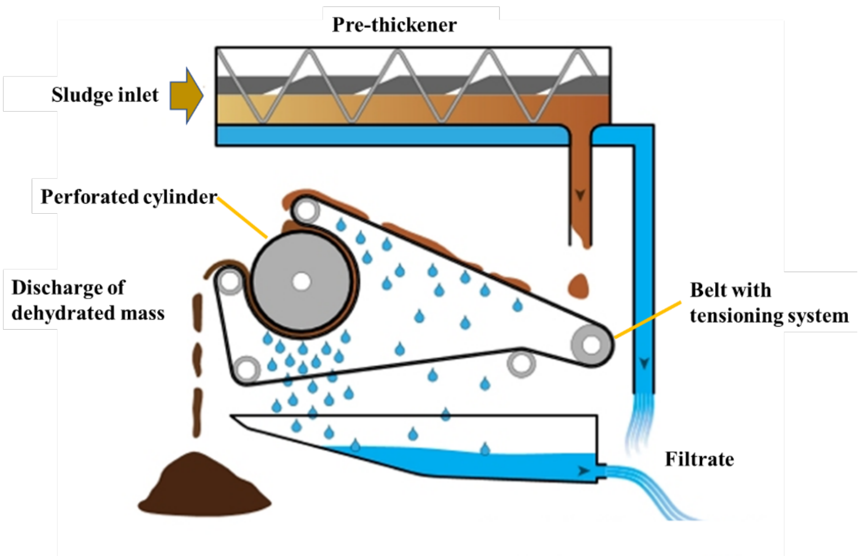

Figure 44. Simplified scheme of belt filter press[31]

The area required depends on the press capacity of the belt, normal dimensions: width 3–6 metres; length 5–10 metres; height 3–6 metres, including the area required for maintenance. This equipment can only be installed indoors.

[31]www.technofangi.it

Dewatering result

The result of dewatering is worse than mingling with a centrifuge. Primary sewage sludge may be dehydrated to a dry matter content of approximately 30–35 %, mixture of primary and surplus sewage sludge up to a dry matter content of approximately 24–30 %, aerobly stabilised sewage sludge up to a dry matter content of approximately 15–22 % and fermented sewage sludge up to 20–28 %.

With belt presses, sewage sludge typically deters up to 13–16 % of dry matter.

Operators of WWTPs rarely aim to achieve a higher dry matter content in dehydrated sewage sludge, as this would require higher consumption of the polymer, leading to higher dewatering costs. In general, it is considered that the costs of disposing of dehydrated sewage sludge are low enough and that wastewater sludge does not pay up to a higher percentage of dry matter.

The effectiveness of dewatering is not so much **determined by** the press pattern of the belt or the year of manufacture, but by the nature of the sewage sludge in the particular WWTP, the brand and dose of the polymer selected, and by the operator's ability to adjust the dewatering process.

Operation and maintenance

The belts are intended for continuous operation (24/7), but it is also possible to organise work in shifts (8 or 16 hours a day for five days a week). It is recommended to use a buffered container equipped with a stirrer, but if the press is not operated continuously, the volume of the buffering tank should be increased. The buffer tank guarantees the stability of the process. A direct feeder is also possible.

The belt presses are simple in exploitation, they do not have fast-rotating parts and do not need expensive and sophisticated repairs. Filter presses do not have much descending parts that would require a regular replacement: periodic changes of the slide bearings and the nozzles of the belt washing system. Both of these components are not expensive. After a relatively long period (at least 5–10 years of work), the filter belt should be changed.

If the belt press regularly undergoes preventive maintenance, it is a secure facility.

Local control panels and remote controls allow easy adjustment and control of the belt filtering presses. Regulating the filter press is relatively simple and does not require high personnel qualifications.

Costs

The cost of capital is between EUR 80 000 and EUR 250 000, depending on capacity. The operating time of the equipment is normally 15–20 years. Investment costs can rise if a scent suction cover is installed or the performance of individual sections is increased.

The installed capacity is approximately 20–50 kW, electricity consumption is approximately 4–9 kWh/t dry matter. The electricity consumption of this plant is negligible compared to the total electricity consumption of the WWTP.

If we assume that the electricity price for water holdings is approximately EUR 0.15/kWh, then at 4–9 kWh/tonne dry matter the electricity costs for dewatering waste water sludge with belt presses are approximately **EUR 0.,60–EUR 1.35/tonne dry matter**.

In theory, dewatering excess sewage sludge with the ribbon presses requires about the same polymer consumption as dewatering with the screwing presses, but compared with centrifuges, it is higher. If the objective is to reach the maximum dry matter content in dehydrated sewage sludge, the normal consumption of the polymer when working with the ribbon presses shall be 8–12 kg of polymer per 1 t of wastewater sludge dry matter. If a lower dry matter content is allowed in dehydrated sewage sludge, the consumption of the polymer shall be reduced accordingly. Assuming a polymer price of EUR 3.00/kg and a polymer consumption of 3–10 kg/tonne dry matter, we get that the cost of the polymer when dehydrating sewage sludge with belt presses is approximately **EUR 9–30/t dry matter**. The total operating costs in the case of a typical electrical consumption of the belt press are summarised in Table 22.

Table 22

Total Cost of Dewatering Sewage Sludge with Belt Press

Electricity costs, EUR/t dry matter	Polymer costs, EUR/t dry matter	Total costs, EUR/t dry matter
0.48–1.08	9.00–30.00	9.48–31.08

When dehydrating excess active sewage sludge with belt presses, **the polymer** costs are significantly (at least ten times) higher than electricity costs and **represent approximately 95 % of the total direct costs of dewatering sewage sludge.**

4.3.3.9. Summary of the most common wastewater sludge dewatering technologies in Latvia

A comparison of the characteristics of the most common wastewater sludge dewatering equipment in Latvia is summarised in Table 23. The comparison has been made in accordance with the information set out in the previous chapters. As disc press technology is used relatively rarely in Latvia, certain columns of the table lack information about their actual performance under Latvian conditions.

On the other hand, an overview of the benefits and disadvantages of technologies is shown in Table 24. The comparison of equipment shows that each of them has its own advantages and weaknesses. In the selection of wastewater sludge dewatering equipment, linking their parameters and working arrangements to wastewater treatment plants and the technological scheme for the treatment and disposal of sewage sludge is essential.

Table 23

Comparison of Dewatering Equipment Technologies

Criterion	EQUIPMENT			
	Centrifuge	Screw press	Disc press	Belt press
				
Use	In large WWTPs, medium and small machines (mobile)	Recommended up to CE 50 000	Small WWTPs	Small WWTPs (mobile)
Technology		Simple design Wide-ranging regulatory options		Simple design Limited regulatory options
Fitness	For dewatering of fermented or aerobically stabilised sewage sludge	For dewatering of fermented sewage sludge		For dewatering of fermented sewage sludge
Dewatering result, %	18–24 %	10–14 (max. 20 %)	Up to 15 %	13–16 %
Operation and maintenance	Demands increased attention	Simple in operation	Simple in operation	Simple in operation
Environmental aspects	There are no specific environmental problems. Possible high noise level	No special environmental problems	No special environmental problems	No special environmental problems
Capital costs, EUR	100 000–250 000	100 000–150 000		80 000–250 000
Set power, kW				20 –50
Electricity consumption, kWh/t dry matter	90–200	4–12		4–9
Electricity costs, EUR t/dry matter	10.80–24.00	0.48–1.44		0.48–1.08
Polymer consumption, kg/t wastewater sludge dry matter	3.7–12	8–12		8–12
Polymer costs, EUR/t dry matter	11.1–36.0	15.00–36.00		9.00–30.00
Total costs, EUR/t dry matter	21.9–60.0	15.48–37.44		9.48–31.08

Table 24

Comparison of Advantages and Disadvantages of Dewatering Equipment

Criterion	EQUIPMENT			
	Centrifuge	Screw press	Disc press	Belt press
				
Advantages	Compact equipment. Possibility of working without reagent schemes and using floculants. Greater dry matter in dehydrated sewage sludge and lower polymer consumption compared to other equipment mentioned here.	There are no externally rotating components. Consumes far less electricity than centrifuges. A significantly better degree of dewatering compared to the band-type presses may be provided. Spare parts cost less than centrifuges. Simple and easy to monitor.	Simple and easy to monitor. Low energy and water consumption.	There are not many and quickly descending parts and knots. Low electricity consumption. Do not remove large-size inlets and sand from the sludge Simple in operation. Do not require expensive and complicated repairs.
Disadvantages	The need to separate large-size inlets and sand from the sludge. Periodic clamshell screws welding or replacing.	Demands skilled labour. The polymer brand should be carefully selected and the work fluid should be prepared qualitatively. Spare parts cost higher than belts for presses. Polymer consumption higher than with centrifuge.	Skilled labour needed. Requires a carefully selected polymer brand and high-quality preparation of the work liquid. Spare parts cost higher than belts for presses. Polymer consumption higher than with centrifuge	Larger in size than centrifuges. Potential for removal of odours. Periodic replacement of filter fabric. High water use for flushing.

4.4. Recycling of sewage sludge

Sewage sludge is composed of an organic mass, which decomposes as a result of the action of micro-organisms. It may be processed by means of controlled biotechnological processes where a partial or complete transformation of biodegradable substances is underway — bioconvergence. Biological processes must be provided with a temperature and humidity regime appropriate to the growth of micro-organisms, the pH of the environment.

Depending on whether the sewage sludge is processed anaerobically or aerobically, the oxygen-free environment is required in the first case, but in the second case the process must be provided with the corresponding amount of oxygen.

There is also a need for monitoring and optimising the parameters needed to support other processes.

4.4.1. Treatment in sewage sludge fields – cold fermentation

Treatment of sewage sludge in sewage sludge fields, or cold fermentation, is one of the aerobic processing techniques of sewage sludge.

THE OBJECTIVE is to recycle sewage sludge into organic fertilisers that can be used for soil enrichment, both in agriculture and in greening and elsewhere.

According to MK Regulation No. 362, sewage sludge is considered to have been recycled if it has been stored (aged), including in liquid form, for at least 12 months (cold fermentation) without mixing and displacement during storage. During this period, sewage sludge is both hungry and passing through the summer of heat treatment cycles.

The storage period of sewage sludge must not exceed three years.

According to MK Regulation No. 362, sewage sludge stored for more than three years is classified as waste and should be subject to waste management legislation.

Wastewater sludge drying fields (Figure 45) worldwide have been known and widely used in municipal and municipal wastewater recycling for more than 100 years. Although such wastewater sludge drying fields work most effectively in warm and sunny areas, they are also used in wastewater treatment plants in the northern climate zones, where not only sludge drying is carried out, increasing the dry matter but also partly hyphenating them.

Figure 45. Open wastewater sludge drying fields[32]

Fitness

Both dehydrated and undehydrated sewage sludge may be recycled. Equipment of different capacity and different types of waste water treatment may be used

Advantages and disadvantages

Advantages	Disadvantages
Low capital costs	Insufficient drying process is provided, as it is affected by precipitation
Low energy consumption	Prior stabilisation of sewage sludge is required
Low operating costs	Foul odours are released during transshipment and transport
Low polymer consumption, as no high dry matter content is required	Needs significant space/area for treatment of sewage sludge
No special operator skills and additional workforce required	Insufficient improvement of hygienic properties
May be used in agriculture	Not recommended for use in food cultivation

Technology

There are many variations in design, including a different layout of drainage pipelines, the thickness of gravel and sand layers, and the way construction materials are used. The most commonly known and most frequently used in the conditions of Latvia are wastewater sludge drying fields with solid base, redundant water drainage layer and drainage water collection system (Figures 46 and 47).

[32] https://commons.wikimedia.org/

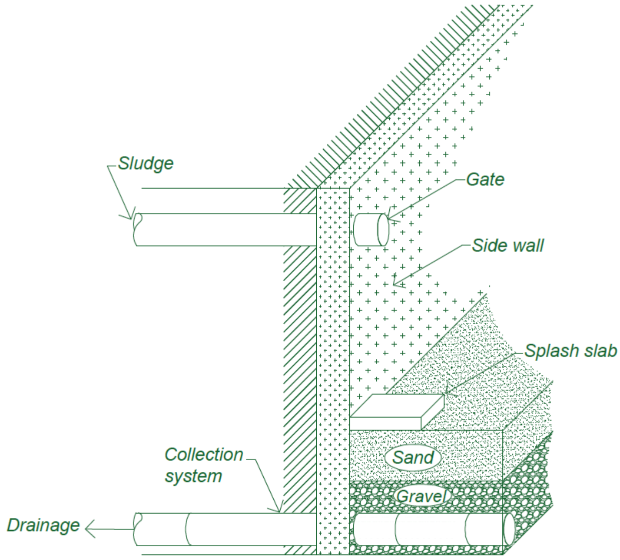

Figure 46. Traditional wastewater sludge drying field with sand base[33]

Over a layer of fragments of 200 to 460 mm, cover a layer of sand of 230 to 380 mm. A thickening layer of sand provides a good quality of the filtrate and reduces the frequency of the sand layer replacement, which can lead to a decrease in the sand layer as a result of its cleaning. However, a deeper layer of sand usually delays the drainage process. The effective diameter of the sand is normally between 0.3 and 0.75 mm and is less than 4.0. Gravel is normally classified with an actual diameter of 3 to 25 mm.

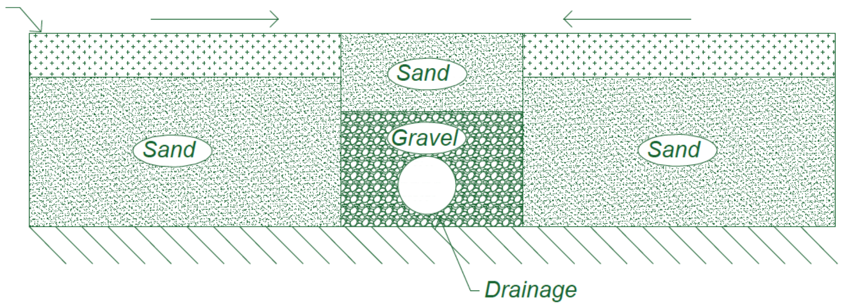

Figure 47. Cross-section of the wastewater sludge field with solid base (asphalt or concrete)

Drainage pipes shall be made of perforated plastic or ceramic pipes installed with open connections (no spacers) to avoid damage to pipes, taking into account the type of vehicle used during the removal of sewage sludge. The diameter of the tubes shall not be less than 100 mm and shall have a minimum inclination of 1 %.

In general, sewage sludge is applied to the field by means of pressure lines. In the development of wastewater sludge drying fields, provision should be made for the possibility of flushing the pipelines and, if necessary, preventing them from freezing in cold weather. It

[33] *Metcalf & Eddy, Inc. Wastewater Engineering: Treatment and Reuse. Boston: McGraw-Hill, 2003.*

should also be noted that a mechanism must be provided to protect the base of the field from erosion at the time when sewage sludge falls onto the ground of the field.

There may also be partially or completely closed sewage sludge drying fields (Figure 48) allowing the dewatering of sewage sludge throughout the year, regardless of the weather. The additional advantage of closed fields is the possibility of reducing the spread of odours from sludge processing. It is possible to use transparent design materials to maximise the use of solar thermal energy for evaporation of excess water in the same way as in greenhouses. Fully covered sewage sludge drying fields require an area of approximately 25 to 30 % lower than open fields.

Figure 48. Covered fields for greenhouse sewage sludge drying[34]

In covered sewage sludge fields, sewage sludge is not exposed to the effects of precipitation. Unlike exposed sewage sludge fields, where sewage sludge is usually wet during treatment (the dry matter content is declining) and the amount of sewage sludge to be exported increases, the dry matter content of sewage sludge in the covered sewage sludge fields during treatment increases slightly, and the amount of sewage sludge to be exported is decreasing slightly.

The simplest criterion for the size of the sewage sludge field is the unit load in kilograms of dry matter per square meter per year for a particular type of sewage sludge, taking also into account climatic conditions (temperature, wind speed and precipitation), as well as the characteristics of sewage sludge, such as sand, fat, organic matter content and concentration.

The greatest hygenic effect of sewage sludge is the incorporation of sewage sludge into a thin layer at a thickness of 30–40 cm, which is dying in winter, heating and evaporating during summer.

Thickening is not recommended because the deepest layer does not eat sewage sludge.

The optimal load on dry matter should be 10 to 15 kg dry matter/m^2 when placing a layer of this thickness. The total required drying time depends on the desired dry matter content to be reached. In addition to water spilling through the sand layer, the humidity is reduced, also by evaporating it. The time needed to evaporate moisture is significantly longer than the time needed for drainage. Therefore, the period for which sewage sludge must be located in the field for the drying of sewage sludge shall be determined by the amount of water to be reduced by

[34] www.huber.de

evaporation of the sludge. The drying time is shorter in areas where there is little precipitation and humidity but more sun.

> Under favourable conditions, sewage sludge may dry up to approximately 40 % of dry matter after 10 to 15 days.

Natural freezing and thawing of sewage sludge in the cool northern climate enhance the dewaterability of sewage sludge. Dried sewage sludge has a coarse, cracked surface and is dark brown. Sewage sludge dried in small WWTPs is usually removed by manual piling up and exporting by truck. Major WWTPs shall use frontal loaders or special mechanical removal equipment for dried sewage sludge.

During cold fermentation, the amount of sludge is reduced at the expense of evaporation of water. If chemical coagulation agents are used to link sewage sludge, evaporation is very slow and the water content in the deeper layers of sewage sludge may remain unchanged or even increase. Organic substances shall be degraded to a minimum or during anaerobic processes when methane gas is released.

The physical properties of sewage sludge are slightly improved during storage: it becomes dryer and, as a result of freezing, less binding (easier to use with manure bouncers). The chemical properties of sewage sludge do not improve during treatment. Mineral nitrogen turns into the form of ammonium salts. The concentration of heavy metals remains at the appropriate level or decreases slightly as a result of leaching.

Environmental aspects

There is no marked unpleasant aroma during processing. During the storage of sewage sludge, anaerobic processes of methane and other greenhouse gases take place in the deeper layers of the mass. Animals and insects, which are associated with nutrients in the mass of sewage sludge, may carry diseases. During transshipment and transport of sewage sludge, there is an unpleasant smell consisting mainly of reduced sulphur and ammonia compounds. Hungry sewage sludge mostly does not undergo complete hygiene.

Use of stored sewage sludge

Dehydrated long-stored sewage sludge is a viscous mass, having a density of 1.0–1.2 kg/l. The surface of sewage sludge usually deminates better. Such sewage sludge shall be transported in watertight cargo cases, which may be open because the sewage sludge is semi-solid and free. Sewage sludge stored in accordance with Latvian regulations may be used in agriculture, greening, recuperation of degraded areas. In view of the fact that the hygienic properties of sewage sludge do not improve significantly during storage, it is not recommended to use a food crop used in foods without heat treatment in areas intended for cultivation or to do so at least one year before the cultivation of food crops.

Costs

The costs of storage of sewage sludge consist of:

1) capital investments for the construction of a storage area, including the water-tight area base and drainage system;
2) transshipment and transport of sewage sludge from WWTP;
3) electricity costs for pumping filtration water back to WWTP.

The average cost of treating sewage sludge when stored is 0.06–0.10 EUR per 1 m^3 wastewater or approximately 300–500 EUR per 1 tonne of dry matter in WWTP plants with a load of PE 2000–10 000.

4.4.2. Composting

Composting is an aerobic decomposition process aimed at stabilising organic materials and waste, as well as producing hummus (compost). Composting is a simple and tested technology that is used for the recycling of sewage sludge and for the production of a valid product, compost.

OBJECTIVE: to recycle sewage sludge into organic fertilisers that can be used in agriculture, greening and other soil wells.

One of the most important characteristics of organic substances of natural origin is the ability to compost water, minerals, nitrites, nitrates, heat and humus-like products as a result of aerobic processes of biodegradability.

According to MK Regulation No. 362, composting is a process during which at least three days the temperature inside the stack, 50 cm from the surface of the pile, is not less than 60 ºC.

The composting process involves a variety of bacteria, algae, mushrooms, worms and other groups of organisms. Composting improves the physical and chemical properties of the material, oxidizes toxic organic compounds, while heavy metals form poorly soluble compounds. The properties of sewage sludge and the potential concentration of toxic impurities are also important factors for the success of the process.

Fitness

Both dehydrated and undehydrated sewage sludge may be recycled. Different loads and different wastewater treatment plants can be used

Advantages and disadvantages

Advantages	Disadvantages
Composting does not require particularly high dry matter in sludge, so wastewater sludge suitable for composting can be dehydrated by screws for press and centrifuge as well as by well-adjusted and properly operated filtering presses	Large investments to build a plant
May be used for both large and small amounts of sewage sludge	Areas of specific size are required
Advantages	**Disadvantages**
High-quality composting process will significantly reduce the amount of pathogenic micro-organisms	Composting fillers become less accessible and more expensive

Compost is biologically active, suitable for different uses	Relatively high costs of quality compost preparation
Improving the physical and chemical properties of sewage sludge as a fertiliser	Risk of spreading odours by mixing compost
Other organic and inorganic residues may also be used in compost	
Ready compost does not have unpleasant smell	
The capacity of the compost plant may be rapidly increased or reduced depending on the influx of sewage sludge	
No additional workforce or special skills required	

Technology

Composting is widely used for composting in open stalls (wind lines) or tunnels, closed compost plants, where accelerated processing processes take place, in enclosed hangars where different odours are eliminated qualitatively.

For the preparation of compost, wastewater sludge may be used as treated and not treated. Where the dry matter content of sludge is less than 15 %, the preparation of compost is difficult.

Compost may be prepared on a watertight surface tarred or concrete area where appropriate gravity machines can move (Figure 49). It is desirable to create asphalt surface with increased strength, taking into account the intensity and specificity of heavy machinery. The slope of the base in the composting and original mass storage area must be 2–4 %. It is necessary to ensure that drainage water is collected around this area.

The size required of the composting area shall be calculated on the basis of the amount of mass to be composted.

Figure 49. Compost preparation area in Liepāja WWTP[35]

[35] *"Liepāja Water"Ltd. archive*

Compost piles – studs – must be large enough to provide optimal heat, but at the same time the piles must also contain sufficient amount of air. Treatment technology (Figure 50) is normally used for the composting of sewage sludge. In this case, the width of triangular studs at the base is 7.5 m and a height of 3.3 m, depending on the mixing technique used. Building larger studs provides a more stable temperature in compost mass. In length, studs may be as long as the area concerned permits.

In order to obtain high-quality compost, it is necessary to ensure that the surface is smoothed, by intensively mixing compostable material and aerating piles. During the first week after the processing of the raw materials, they shall be mixed in the compost markets every day until a loose uniform mass is obtained. During this period the mass of compost shall be heated at least up to 70 °C, provided that suitable material is used and added in the correct proportion. Reshuffle can then be repeated twice a week.

Figure 50. Building of composting studs in Liepāja WWTP[36]

The technique used for mixing studs is one of the main factors for obtaining good quality compost. Self-propelled or tractor-pulling units shall be used for mixing the compost. In recent years, the number of companies producing composting equipment and technical solutions has increased rapidly.

Raw materials

Fillers shall be used to ensure the required quantity of dry matter and nutrients in compostable mass. Wood residues of different composition, including sawdust (Figure 51), chips, shredded bark and branches, fallen leaves, peat (Figure 52), straw, marine manure and other non-hazardous organic residues may be used as a filler.

[36] *"Liepāja Water" Ltd. archive*

Figure 51. Completion material for compost – sawdust[37]

Figure 52. Compost material – peat[38]

If peat is used for the preparation of compost, it must be taken into account that acid compost is formed, so its use may be limited.

Process

The use of aerobic processes for the recycling of sewage sludge makes it possible to significantly reduce the amount of pathogens in mass, since the heat released during the oxidation reaction and consequently the increased temperature of up to 60–70 °C destroys the majority of pathogenic micro-organisms and hygienise it. The microbiological process for compost development takes place in a wide range of environmental reactions ranging from pH 5.5 to pH 7.6, but nitrification processes are most active when pH is 6.8 to 7.3. The compost humidity decreases during aerobic processes, with an optimal humidity of 50–60 %. Therefore, wet sludge should initially be accompanied by a dry organic mass, but further composting should be further moistened if necessary.

An important measure of the intensity of the composting process is C:N (carbon-nitrogen ratio). The desired C:N ratio for the success of microbiological processes should initially be in the range of 35–30:1.

In order to be able to obtain maximum quality compost, four appropriate phases of action should be implemented when preparing it.

[37] *"Liepāja Water" Ltd. archive*

[38] *"Liepāja Water" Ltd. archive*

1) Soil warming phase.

At the beginning of composting, the temperature in the prepared material starts to rise slowly. The maximum temperature that can be achieved in the composting process is above 70 °C. In this state, the pathogenic bacteria, fungi and helmint eggs, which are present in compostable material, are destroyed. Warming begins on average on the third day after the process is activated and continues for two or three more weeks.

2) Aeration phase.

Gases are starting to occur in this phase. The compostable material must be aerated sufficiently to ensure the required oxygen and optimum humidity of its entire volume. Compliance with these conditions shall ensure the reproduction of the required microflora. If the humidity is too low and the temperature starts to rise rapidly, the mass must be moistened. After two to three weeks, the temperature within the composting mass begins to decrease to 30 °C. At this point, soil bacteria and fungi that contribute to the degradation of organic matter and start producing CO_2 gas, as well as ammonia and methane, are beginning to multiply rapidly.

3) Structuring phase.

In this phase, structuring and stabilisation of compostable material is underway, hummus and other compost components are formed. Newly created micro-organisms are actively consuming nitrogen to build the proteins they need.

4) Maturing phase of compost.

The final establishment of compost takes place in the following 6 to 9 months. It is not recommended to keep compost for longer, because it only contributes to partial mineralisation of organic substances, so compost loses quality.

Compost, unlike sludge, forms a loose soil-like structure, is easily transportable and workable. Well-prepared compost does not have an unpleasant flavour, spreading of odours during the composting process can be avoided by avoiding from the formation of anaerobic conditions.

Quality

At the end of the composting process, it must be verified whether the compost is prepared and its chemical and microbiological characteristics or not containing harmful compounds. In order to obtain a quality product, materials to be recycled must meet the following conditions:

1) the content of heavy metals and other pollutants must not exceed the regulatory requirements;
2) they must not contain any impurities of plastics, glassware, etc. which are not processed during the process.

The quality requirements for compost are laid down in MK Regulation No. 362.

The quality of sewage sludge and compost is guaranteed by the compost manufacturer. The quality of compost shall be determined for each compost series (mass of compost composed of sewage sludge and effluent materials and at the beginning of composting does not exceed 1000 tonnes). For this purpose, a single average sample is consisting of at least 25 individual samples.

The producer of wastewater compost shall, on the basis of the resulting quality indicators of sewage sludge and compost, draw up an appropriate quality certificate for each compost series in accordance with Annexes 3 and 4 of MK Regulation No. 362 (hereinafter the – quality certificate).

Producer of sewage sludge and compost:

1) registers the quality certificate for each series in a special registration journal (Annex 5);
2) keeps wastewater compost quality testing reports and original quality certificates, as well as registration journals for a period of not less than ten years.

The producer of sewage sludge and compost shall issue a copy of the quality certificate to the compost user.

Compost of typical fully recycled sewage sludge:

1) loose, uniform, particle size not exceeding 120 mm;
2) humidity 60–70 %;
3) with a low alkaline or neutral environmental reaction (pH not less than 6.0);
4) nutrients are in the form to be absorbed by plants and constitute not less than 50 % of the total composition;
5) contains 25–35% dry matter, approximately 0.6 %N, 0.2 %$P_{2}O_{5}$ and 0.6 %$K_{2}O$;
6) it no longer contains helminot eggs, larvae, and pathogenic micro-organisms and sproutable weed seeds at a dangerous concentration.

Environmental aspects

In the process of preparing compost, sewage sludge is diluted with other components, so the weight share of heavy metals is decreasing, and these elements form insoluble compounds in the composting process. Other illiquid agents, traditionally disposed or burned – shavings, are also used for composting. The use of compost as a fertiliser improves the soil structure by bringing organic matter into it. If the composting process is carried out as expected by technology, hydrogen sulfide compounds do not form but ammonia NH_3 is released. Therefore, during composting, odours are released, which can be reduced by the use of appropriate technologies. If the right technology is used to keep the temperature needed for composting, the pathogenic micro-organisms that are unable to survive at high temperatures are killed.

If all conditions for the preparation of compost are not met, the following risks are present:

1) temperature is too low: the process is slow and pathogenic micro-organisms are likely to survive if they were in the raw material of compost;
2) insufficient mass of aerated compost – hydrogen sulfide forms in the process of incomplete organic matter degradation and its compounds – odours arise;
3) where the area is not suitable for the process concerned, the compost mass soluble substances, including small amounts of heavy metals, may be introduced by rain water from the mass of compost in groundwater;
4) if the mass of the compost is not regularly stirred, weed seeds are sprouting in the compost pile and they enter the finished mass of compost.

Use of sewage sludge compost

The use of wastewater sludge compost is significantly more extensive compared to untreated sewage sludge. Compost may be used:

1) for greening;
2) for the installation of the surface of sports areas;
3) for fertilising plants, including for the preparation of a substrate for sub-plants;
4) for lashing of tops and embankments;
5) in agricultural and forest-based fertilising;
6) for recovery of contaminated and degraded soils;
7) for the recultivation of municipal landfill sites;
8) for preparing the plant substrate for indoor plants.

Soil cultivation in agriculture

In accordance with MK Regulation No. 362, treated sewage sludge may be used for soil manure in agricultural areas, as well as compost prepared from treated or untreated sewage sludge, for which the mass concentration of heavy metals in the dry matter does not exceed the limiting concentration referred to in Annex 9 of MK Regulation No. 362 (Table 24). Sewage sludge and compost may be used for soil manure even if the mass concentration of not more than three heavy metals exceeds the limiting concentrations by not more than 10 %.

Table 24

Limit of Mass Concentration of Heavy Metals for Soil Manure and Recultivation or Disposal in Municipal Waste Landfills and Landfills for Wastewater Sludge and its Compost

No.	Heavy metals	Mass concentration in dry matter, mg/kg
1.	Cadmium (Cd)	10
2.	Chromium (Cr)	600
3.	Copper (Cu)	800
4.	Mercury (Hg)	10
5.	Nickel (Ni)	200
6.	Lead (Pb)	500
7.	Zinc (Zn)	2500

Costs

The total costs of composting can be divided as follows: approximately 1/3 is investment, 1/3 is transport costs, and 1/3 is the costs of composting process. The capital costs, depending on the capacity of the mixing machine, the area of the composting area and the amount of sewage sludge processed in compost, range from EUR 500 000 to EUR 3 000 000, the planned area of sludge from 2000 to 29000 m^2. Capital costs consist of the installation of a plant that consists of a watertight area, the construction of a drainage water collection and pumping system, tarred driveways, the construction of a closed hangar, the introduction of odours prevention technology, compost preparation equipment and management equipment, etc.

The costs of producing compost are approximately 10–12 EUR per 1 tonne and the main lines of expenditure are:

1) the costs of the added material;
2) operational costs of specialised machinery;
3) moulding and mixing;
4) process control;
5) quality testing analyses;
6) loading and transport of compost;
7) administrative costs and salaries of employees.

The higher is the amount of compost produced, the lower are the production costs of 1 t of compost.

A simple composting process does not require electricity or chemicals because of the use of mobile technique.

World practice also uses more sophisticated composting techniques, where electricity is used, for example, by blowing air into droves with air blowers the compost is produced in greenhouse buildings using a variety of rotors, blowers, etc.

Despite the need to use specialised techniques for mixing, there is no need for additional labour or specific skills, other than those required for day-to-day work. However, in order to obtain quality compost, the worker must have experience and a tractor driving licence.

4.4.3. Fermentation of sewage sludge – production of biogas

Anaerobic sewage sludge recycling or anaerobic fermentation is a process of methane fermentation in which microbiologically degradable organic substances decompose in an anaerobic environment by producing a biogas with a basic methane component. Anaerobic fermentation is one of the oldest and most commonly used techniques for the stabilisation of sewage sludge. Organic and inorganic substances concentrated in sewage sludge are microbiologically distributed without oxygen and converted into methane and inorganic final products.

OBJECTIVE: By reprocessing sewage sludge to obtain biogas as an energy resource and improve the quality of wastewater sludge to be disposed of, and minimise biological and chemical reactions.

Methane is a gas the molecule of which consists of one carbon and four hydrogen atoms (CH_4). Methane is the main ingredient of natural gas. Its calorific value is approximately 70 kcal/1 m^3. Natural gas is a fossil fuel formed several hundred thousand years ago, as a result of organic matters decomposing in anaerobic conditions. Natural gas is usually found in oil and coal deposits.

The main positive results of fermentation are the stabilisation of sewage sludge, the reduction of volume, and the occurrence of biogas.

Biogas produced in methane tanks consists of methane (50–80 %), carbon dioxide (20–50 %) and small amounts of other gases (hydrogen, carbon monoxide, nitrogen, oxygen and hydrogen sulfide). The amount of impurities in biogas depends on the composition and technological process of sewage sludge.

Fitness

Anaerobic fermentation is used mainly in medium and large WWTPs. As with all processes for the treatment of sewage sludge, the characteristics of the sewage sludge to be treated are crucial for fermentation. Primary sewage sludge is more easily fermentable and deminated compared to excess sludge containing bacteria. Digestion of excess sewage sludge takes longer. The required pretreatment of sewage sludge prior to its recycling in methane tanks depends mainly on the type and quality of sewage sludge. The most commonly used dewatering method is compaction, usually mechanical, to provide a higher dry matter content.

In order to ensure that the use of sewage sludge for biogas is targeted, the content of dry matter must be 4–7 %.

Advantages and disadvantages

Advantages	Disadvantages
Prevention of pathogenic contamination	Large initial capital investments
Odours are reduced	Qualified personnel required
Seasonality does not affect the production of biogas	Regular process monitoring
Dry matter content in the sludge supplied does not need to be high (4–7 %).	You need to get many and different permissions
	The process of obtaining biogas results in the development of (sate, for which additional technologies must be used for full processing but for which there are major investments involved, where there is no WWTP with high degree of overcapacity in the vicinity.

Technology

The efficient operation of methane tanks (Figure 53) requires a large amount of sewage sludge, and it is therefore recommended that wastewater sludge be recycled together with other raw materials, for example in cooperation with farmers.

Biogas plants shall consist of the following main systems:

1) preparation and administration of raw materials into a bioreactor;
2) a bioreactor with constant temperature maintenance and mixing devices;
3) purification, storage and use of biogas;
4) unloading, storage, processing and use of a digestat.

Methane tanks/bioreactors are usually concrete or steel tanks (depending on the volume and material costs of methane tank), most often located above the ground, and are isolated to maintain a uniform temperature in the metal.

For a relatively long period of treatment, the fermentation of sewage sludge requires large reactors that take up a lot of space. In addition to the reactor tank(s) that balance fluctuations in the production of biogas, the biogas produced must also be stored somewhere and additional area is needed for that purpose. As a general rule, the diameter of the reactor and the gas accumulator is 6–15 m, and the area required for large wastewater treatment plants for the fermentation process is approximately 25–35 m x 30–40 m. All reactors can be parked outside, but they need to be isolated. Pumps and other auxiliary equipment should be placed inside, usually under the reactors or in separate pump rooms.

Figure 53. Various forms of bioreactors in Lübeck, Germany[39] and Riga[40]

All methane tanks have the same basic structural elements, a mixing chamber, a closed methane tank where biogas is forming, a system for using biogas and a system for the removal of sewage sludge. Methane tanks shall always be equipped with mixing and heating equipment which allows for a good mix of sludge and a constant temperature. The fermented sewage sludge may be removed from the tank by pump or self-flow.

In practice, two types of methane tanks are mainly used: with discontinued and continuous activities. Dashed-action methane tanks are simpler. They shall inject a certain amount of sewage sludge and leave it to decompose. The treatment time depends on temperature and other factors.

Sewage sludge from continuous activities methane tank is gradually injected into the methane tank compartments. The material to be processed moves along the methane tank by means of transporter or under pressure of the new batch of sewage sludge. Unlike discontinued methane tanks, this type of equipment produces biogas continuously. They are suitable for larger wastewater treatment systems.

Process

The anaerobic fermentation process can take place in both mesophile (approximately 35–40 °C) and thermophile temperature (53–57 °C). The main advantages of thermophilic treatment are higher wastewater sludge handling capacity and more complete dewatering, as well as higher sanitary quality of treated sewage sludge. The shortcomings of the method are higher energy costs and a lower quality of fugate in which the presence of suspended substances is

[39] https://entsorgung.luebeck.de/
[40] "Rīga Water" Ltd. Archives

observed. Thermophilic fermentation, compared to mesophilic, creates a stronger smell, and the process is less stable. For more than 30 years laboratory and practical experiments have been carried out to find the possibility of fermenting municipal sewage sludge at thermophilic temperatures, but unfortunately there are no practicable results for these experiments. The large energy consumption is the most common problem, so thermophilic fermentation is only suitable for areas with warm climate[41]. Further on, this handbook deals only with fermentation in the mesophilic temperature range. The main advantages of the mesophilic fermentation process are the stability and quality of the process and safe operation.

Fermentation takes place in one or more methane tanks that can be filled both simultaneously and in succession, with a typical passing time between 20 and 25 days.

The minimum allowable passage time is approximately 14–15 days, as the shorter passing time usually decreases gas production.

There are processes with a small organic mass dry matter content (8–12 %) and with high dry matter content (>22 %).

It should be noted that the amount of water in the wastewater sludge mass to be recycled at the beginning of gasification is also maintained at a later stage.

It should, therefore, be biocleaned or, where appropriate areas are available, it should be used for the fertilising of agricultural land when released on the field. Decomposition of organic substances under anaerobic conditions is a complex process. This occurs in three stages as a result of the operation of different micro-organisms.

1) Phase 1
   Acids, alcohols, gases, amino acids, glycerol, etc. are produced in the presence of water. This division is carried out by conventional saprophiles or hydrolytic bacteria, which are widespread in nature, rapidly growing and living in a medium-acid environment with a pH of 4.5–7. Sour ferment is characterised by acid formation, acidification of the environment and unpleasant odours.
2) Phase 2
   Acidogenic micro-organisms continue to decompose substances and make acids. The main substance from which methane is produced is acetic acid (around 72 %).
3) Phase 3
   Methane-forming micro-organisms use preformed substances. CO_2, CH_4, H_2, N and others are released. Anaerobic acidogenic micro-organisms competing with sulfate reducing micro-organisms are present at this stage. Methane tanks are usually predominantly present, and therefore only H_2S is slightly released. The most demanding are methane-forming bacteria. Their growth requires a broad range of nutrients: carbon, phosphorus, nitrogen, sulphur, calcium, magnesium, potassium, sodium, etc., and amino acids, vitamins and trace elements.
   Methane-forming bacteria complete the process by breaking organic acids into methane and other simple compounds.

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[41] Positive wastewater management experience (2012), PURE

The process of decomposition of organic matter is influenced by a variety of factors. The most important one is temperature. In order to improve the process of decomposition of organic substances, constant temperatures should be maintained in methane tanks, as even small variations in temperature may cause significant interference in the functioning of micro-organisms.

The heating of sewage sludge and reactor may be carried out either by conventional heat exchangers and by the recirculation of sewage sludge or by the feeding of sewage sludge into separate parts. The generated heat energy is used for heating wastewater sludge and bioreactor to be supplied. If the temperature of the effluent sludge to be administered is relatively low (5 °C) for a long period of time, the effluent sludge to be delivered is usually warmed in advance in the supply and mixing tank, which is heated, in turn, by a tube or plate heat exchanger and by wastewater sludge recirculation, in order to reach the desired range of mesophilic temperature of 35–40 °C.

Anaerobic bacteria continue to function at 57.2 ºC, but the optimal temperature is 36.7 ºC (mesophilic bacteria) and 54.4 ºC (thermophilic bacteria). The activity of micro-organisms decreases in the temperature range from 39.4 ºC to 51.7 ºC and falls significantly when the temperature is 35.0 °C.

Each dose of sewage sludge shall be heated with steam or hot water in a separate tank and gradually passed to the bioreactor. Wastewater sludge is not required for recycling. In both cases, the additional heating energy needed is produced by the incineration of biogas in a hot water boiler.

The second most important factor is humidity. Processes are taking place more rapidly in liquids. For the dry sludge, the humidity (water) must be supplied in addition.

Other factors affecting the quantity and quality of biogas are pH, dry matter content, carbon nitrogen ratio, homogenisation of wastewater entered, granulometric composition of dry matter and treatment time. Homogenisation of the effluent administered and the crushing of the solid fraction allow the bacteria to function more quickly. In most cases, the pH level in methane tanks is self-regulatory. Sodium bicarbonate may be added to the treated material in order to maintain a constant pH. If the material to be processed is too dry or contains a lot of nitrogen, it shall be diluted with water. The optimum carbon-nitrogen ratio is between 20:1 and 30:1.

If a large number of antibiotics or other substances with bactericidal properties have been introduced into the wastewater, they can kill bacteria in methane tanks, therefore it is important to separate and chemically treat industrial and other wastewater that may contain these substances.

Operation and maintenance

When dealing with biogas, all the same requirements and rules should be taken into account when dealing with natural gas. Working with anaerobic fermentation equipment requires more special skills and adequate qualifications than working with dewatering equipment, such as sealing equipment. Without paying attention to important aspects of the process, this technology is a source of potential odours, biogas is explosive, and therefore a specific set of operational and safety measures needs to be provided.

Operators and maintenance personnel must be well trained for both normal conditions and emergency situations. A work security plan and/or risk prevention plan must be established.

Use of products derived from thermal fermentation of sewage sludge

Sewage sludge

There are many nutrients (nitrogen, mainly in the form of ammonium and organic compounds, phosphorus and trace elements) in sludge formed in methane tanks, and this material can be used to improve soil. The toxic components of wastewater – heavy metals, toxic organic compounds – after processing are concentrated on the degradation of organic matter and the reduction in the mass of sewage sludge.

Digestat

Digestat contains a significant number of nutrients and is suitable for use in rural fertilising and as an additive for animal feed, provided that the harmful elements (heavy metals, helmints, pathogenic micro-organisms) do not exceed the permitted levels. The composition depends on the chemical structure and technological process of the raw materials. Digestat consists of a liquid containing a large number of minerals and organic substances that have not broken down and contain bacterial cells and substances containing a large number of lignins. All major biogenic elements (N, P, K) have remained in the digestat, while N has partially transferred to plants in a readily acceptable form of ammonium. The use of digestat compared to unprocessed sludge makes it possible to obtain much higher yields. If the liquid digestat is incorporated into the soil with a surface-to-surface method, the losses of N are minor.

Biogas, electricity and thermal energy

If optimal conditions are provided in methane tank, anaerobic bacteria will produce biogas continuously. The variation in volume may occur during the administration of the fresh material to be processed. Biogas can be used for heating, in internal combustion engines in motor vehicles, and for electricity generation. If the gas is intended for use in internal combustion engines, it must be removed from hydrogen sulfide (which facilitates corrosion and is toxic). Large systems can sell biogas to natural gas traders, but in this case a complex biogas purification process should be implemented.

Biogas is a renewable energy resource. In cogeneration plants biogas is used to produce electricity and heat at the same time. The distribution between heat and electricity generation is on average 35–41 % electricity and 59–65 % heat. Total losses do not exceed 15 %. The efficiency of electricity generation of modern cogeneration units is higher than 40 %. The thermal energy produced by the superfluous engine or turbine, as well as the thermal energy of the waste gases, may be used to heat the sewage sludge to be fed for fermentation, heated production buildings, as well as for the drying of sewage sludge.

Increasingly, biogas is starting to be used as vehicle fuel. Biogas is normally removed from carbon dioxide gas, hydrogen sulfide and other impurities up to the standard level of natural gas prior to loading into vehicles.

Electricity may be used on the spot or sold to other undertakings, depending on the applicable regulatory enactments.

Costs

The necessary capital investment for the construction of a single full-cycle sewage sludge recycling and biogas production plant is between EUR 5–15 million, if the estimated amount of wet sewage sludge to be recycled is EUR 130 000–500 000 t/year. In order to reduce the costs of maintenance of methane tanks in winter, it is necessary to find an optimal ratio of temperature and gas production that allows the maintenance of methanic activity without at the same time consuming the majority of biogas produced for heating.

4.4.4. Drying of sewage sludge

Thermal drying is the use of heat to evaporate water from sludge after dewatering. The consumption of energy resources needed for dewatering is much lower than for drying, therefore the dry matter content should be sufficiently high after dewatering. Thermal drying processes, based on the heat energy used to increase the temperature of sewage sludge, are classified into two main categories:

1) Direct (convection drying).
   Heat convection is achieved by direct contact with hot air or carded gases. Typical drying appliances are a rotating drying cylinder or belt dryer. During the drying process, sewage sludge is exposed to approximately 450–460 °C (cylinder) or 120–160 °C (belt drying) temperatures for approximately 5–10 minutes (cylinder) or 40–60 minutes (belt dryer).
2) Indirect (contact).
   A closed wall separates the sewage sludge from heat carrier, usually hot water, oil or steam. Conventional indirect drying machines are a vertical plate dryer and horizontal dryers with disc-shaped, laser-shaped or helical heaters, as well as boiling-layer dryers. For example, heated steam of up to approximately 160–200 °C or up to 190–240 °C heated oil with high thermal stability is used in dryers with dystopian heating elements, while wastewater sludge is aged for 45–60 minutes in the dryer. During drying, the temperature of sewage sludge is 85–95 °C and the exhaust gas temperature is 95–110 °C.

OBJECTIVE: To substantially reduce the water content of sludge and to transfer it to final recycling and/or disposal.

The direct drying method is more efficient and provides more dry matter, but the gas used contains a large number of pollutants, therefore additional filters should be used. There is a risk of explosion in direct drying equipment. Thermal drying results in a reduction in the volume and weight of sewage sludge.

Advantages and disadvantages

Advantages	Disadvantages
Reducing the amount of illiquid material on several occasions	Dust and odours
Reducing transport and storage costs	Mechanical dewatering of sewage sludge is also in place before drying
Total destruction of pathogenic organisms in sludge	Installation of machines only pays off for big WWTPs
Final product suitable for different uses (fertiliser in agriculture and forestry, surface of artificial soil in landfills, quarries, sports areas – easier to transport and use, fuel for power plants and waste incineration plants)	Drying is far more expensive than the mechanical methods of dewatering sewage sludge
Improve the calorific value of sewage sludge and make it possible to use it more effectively for energy production	High electricity consumption, high operating costs
Secondary thermal energy may be used to reduce energy costs	Additional skills and special knowledge on the progress of thermal processes are needed
	Maintenance of explosive areas is required
	Agricultural resource is lost when sewage sludge is incinerated
	Large investments

Technology

Water separation by evaporating from treated and dehydrated sludge increases the dry matter content in sludge and reduces the amount of sewage sludge. Dehydrated sewage sludge is subjected to – primary and/or redundant sewage sludge with a dry matter content of 20–30 %, as well as fermented sewage sludge after dewatering.

The dry matter content in dehydrated sewage sludge is normally between 20 and 30 %. After drying, the dry matter content shall be between 30 and 90 %.

Thermal drying process usually includes handling materials, temporary storage, and prior to drying, the dewatering and fermentation of sewage sludge must be carried out. Thermal drying requires heat generation and distribution equipment, thermal dryer, biological gas filter, after-treatment equipment such as granulator, as well as storage of finished products.

Operation and maintenance

Drying plants must be operated continuously throughout the day, particularly when sewage sludge is incinerated after drying. Even if the finished product is granules, dust may sometimes occur in the air, and therefore, personal protective equipment should be used when handling dried sludge.

There may also be a risk of fire and dust explosion.

In rooms where separate equipment is located, explosion protection measures must be taken. In relation to the fine particles of heat-dried sewage sludge and the high level of drought, the risk of fire and dust explosion may also exist during transportation and storage of sewage sludge. Organic dust flashes rapidly in the air when it comes to the source of ignition.

Use of sewage sludge drying products

As a result of thermal drying, sewage sludge is dried either completely, up to a dry matter content exceeding 85 % or partly to a dry matter content of less than 85 %. Completely dried sewage sludge is used either as powder or as granules. The powder usually goes into the combustion plant, but granulated sewage sludge is much easier to handle. Granulated sewage sludge can be used in agriculture as a rural fertiliser. Since the dry matter content of sludge is 85–90 %, it may be stored in tanks or in large bags.

In the dry sludge for incineration, the dry matter content depends on the balance sheet of the energy and is determined on a case-by-case basis. For mono-combustion without additional fuel use, the minimum dry matter content shall be 45–60 %. Heat-dried material generally meets standard sanitary requirements.

In addition, thermal drying will reduce the amount and weight of sewage sludge. If the dry matter content of sewage sludge is 25 % prior to drying and 95 % after drying, the weight has decreased to approximately 25 % of the original weight.

4.4.5. Other wastewater sludge recycling technologies

Hydrothermal carbonisation (HTC)

Hydrothermal carbonisation is the only thermal sludge recycling method where no prior drying is required. The mechanically dehydrated sludge is heated to approximately 200 °C and treated for several hours in a closed tank, providing appropriate water vapour pressure. In this way, the mass of sludge is divided into three fractions: a mixture of gases (water vapour and decomposition products of volatile organic compounds), a liquid fraction heavily contaminated with nitrogen compounds and a solid fraction of dispersible "lignite". The solid fraction must be dehydrated before being used as a fuel, e.g. in the press of cameras. The gas and liquid fraction become pollution to be adequately cleaned. For this reason, as well as the low value of wet "lignite" fuels, the technology is not popular, although the relatively low temperature and the possibility of directly feeding mechanically dehydrated sludge into the equipment are undeniable advantages. Over the past decade, attempts have been made to create a well-controlled *HTC* process to create much higher value-added carbon-based products – raw materials for the manufacture of plastics or even graphene. If such technologies can be commercially exploited, they can become dominant as they best fit into the carbon chain. Obviously, such technologies will be complicated and will require centralization and use of the large sewage treatment plants where sludge will be treated by collecting mechanically dehydrated sludge from the small plants.

Gasification

Gasification is a thermal process when, in the presence of air or oxygen, combustible materials are transformed into a mixture of combustible gases. In the past, such technology was used for the operation of gas generators and for the gasification of coal. The final products are a process or synthesis gas – combustible gas mixture and slag, ash. For gasification, sludge with a high dry matter content of approximately 80 % should be used, therefore the method is not energy-rational because it cannot be used without additional energy for drying, and therefore the method is not applied in a clean way on an industrial scale. In recent years, however, new technologies have emerged, with increased carbon dioxide from industrial sources and the production of clean hydrogen by electrolysis and the use of renewable resources (wind, sun). They include the simultaneous return of carbon from carbon dioxide over the life cycle as well as the production of higher-quality synthesised gas. However, such technologies have not yet reached the level of industrial use. The methods of gasification differ in the structure of the reactor used.

The composition of gases resulting from gasification varies depending on the composition of the sewage sludge burned. The gas may be used for heating the gasification reactor.

Gasification plants are currently at an experimental stage, so it is difficult to judge their effectiveness compared to incineration technology and other methods of disposing of sewage sludge.

Wet oxidation

The organic portion of sewage sludge is oxidised in special reactors at a temperature of 200–300 °C at a pressure of 30–150 atmospheric levels. The required pressure is achieved by high pressure pumps or in a specially constructed equipment, a pipe drilled into the ground at a depth of 1200 m through which liquid sewage sludge flows down, there is the required pressure and temperature at the bottom, an oxidation process takes place, while mineralized sewage sludge is pumped up the other pipe. This results in a mixture of 95 % minerals and 3 % low-molecular organic compounds. The finished product is dehydrated by a press or centrifuge and deposited or used in agriculture.

This process does not require prior dewatering of sewage sludge.

The water that remains over after oxidation contains very much ammonia, so it should be denitrificated at the site or pumped back to the WWTP.

A number of wet oxidation plants have been installed in the Netherlands, but a number of technical issues have not yet been resolved.

Plasma flame pyrolysis

Sludge pyrolysis takes place at approximately 750 °C in the conditions of oxygen deficiency. The pyrolysis equipment is of a simpler construction than the combustion furnace, but its operation requires a very high dry matter content of at least 80 % in sludge. Pyrolysis gases, when burned in a separate furnace, give some of the heat needed for drying and pyrolysis. As already mentioned, only some of the "hidden" fuel calorific values can be used in this way, so the process requires additional energy from other sources. The other characteristic of pyrolysis is the solid end product, which contains both phosphorus compounds and coke and sand. The phosphorus content in such a mixture is too low for rational industrial recovery, so the whole mixture is used as a fertiliser. Given the high sand content in the dry matter of sludge, the amount of pyrolysis residue is only slightly higher than the amount of ash obtained from combustion. Pyrolysis gases can be burned in a conventional furnace together with other types of fuel. It is possible to create synergies with the heating system. Such technology can be very efficient in small plants.

Several such waste plants (not just sewage sludge plants) were built in the US. The method is not common in European countries.

4.5. Disposal of recycled sewage sludge

This Chapter has been drawn up using materials from the following publications: (1) 16. I. Gemste, A. Vucāns "Sewage sludge", Jelgava: Latvian Agricultural University, 2010; (2) "Positive wastewater management experience" (2012), PURE; (3) D. Lazdiņa. Capacities for the Use of Wastewater Sludge in Bear Plants". Summary of promotion work, Jelgava, 2009; (4) The "Use of sewage sludge and its recycling technologies" has been developed in accordance with the sub-project financed by the European zone financial instrument and the LR budget, "Development of an efficient standard set for the marketing of waste water sludge recycling technologies in Latvia", Association of Latvian Water Supplies and Sewers Companies, 2000.

In Latvia, under the regulatory framework[42], the disposal of sewage sludge is possible in the following ways:

- the use of sewage sludge and its compost for soil enrichment in agricultural land;
- the use of sewage sludge and its compost in forestry;
- the use of sewage sludge and its compost for greening the area;
- the use of sewage sludge and its compost for the recultivation of degraded areas;
- the use and disposal of treated sewage sludge and its compost in landfills and polygons.

4.5.1. Use of sewage sludge and its compost for soil enrichment in agricultural land

The use of sewage sludge and its compost for soil manure in agriculture is one of the most common ways of disposing.

Wastewater sludge in Latvia (taking into account wastewater sludge quality indicators) has a high potential to become a successful part of the circular economy by ensuring the re-use of trace elements in agriculture, thereby reducing the use of fertilisers (e.g., phosphorus).

When using recycled sewage sludge and its compost to correct soils, there are certain contradictions between the wishes of sludge producers and users on the one hand and the environmental requirements on the other. Producers of sewage sludge and sewage sludge users generally are interested in integrating the biggest possible amount of fertiliser into the soil with a higher mass of nutrients. At the same time as plant feed materials, respective amounts of substances harmful to the environment and human health are also introduced into the soil. If these substances exceed certain concentrations, they may become hazardous to the

[42] Cabinet Regulation No. 362 of 02.05.2006, Regulations Regarding the Use, Monitoring and Control of Wastewater Sludge and its Compost.

environment, soil, water and plants. An excessive mass of plant feed materials (mainly nitrogen and phosphorus) can also harm the environment, particularly surface water.

Before taking a decision on the use of sewage sludge and/or its compost in agriculture, analysis of the assessment of sewage sludge and its compost and soil quality should be carried out.

Tests may be performed in a laboratory accredited by the National Accreditation Office of Latvia in accordance with the National Standard EN ISO/IEC 17025 T-261 for heavy metals in accordance with EN ISO/IEC 17025 T-139.

Under MK Regulation No. 362, treated sewage sludge as well as compost prepared from treated or untreated sewage sludge may be used to correct soils for agricultural uses and for which the mass concentration of heavy metals in the dry matter does not exceed the limiting concentration referred to in Annex 9 (Table 24).

The use of sewage sludge may provide the micro-nutrients and nutrients needed for plants (e.g., nitrogen, potassium, phosphorus), while at the same time sewage sludge is a relatively low-grade nutrient source (2–5 % N, 1.2–4 % P, and 0.3–0.5 % K).

For the removal of recycled sewage sludge to agricultural areas, the SPS mostly pays land operators or returns it free of charge, ensuring that sewage sludge is removed or self-discharged; a fundamentally different situation is with sewage sludge compost for which the sale price is fixed.

When analysing the data collected by the Central Statistical Bureau for 2019, it was concluded that cereals and technical crops use a significant amount of mineral manure (Figure 54), which could be replaced at least partly by the use of sludge material.

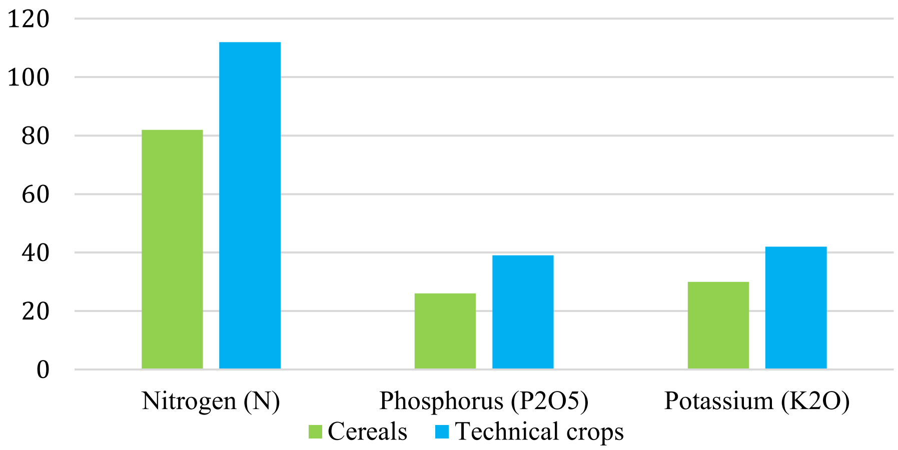

Figure 54. Mineral manure per 1 ha of total area, kg in 2019[43]

[43] http://data1.csb.gov.lv

Sewage sludge and compost may be used for the cultivation of grain and individual legume crops and maize. Information of the Central Statistical Bureau for 2019 shows that the total potential area for sludge and compost is at least 947 500 ha (Figure 55).

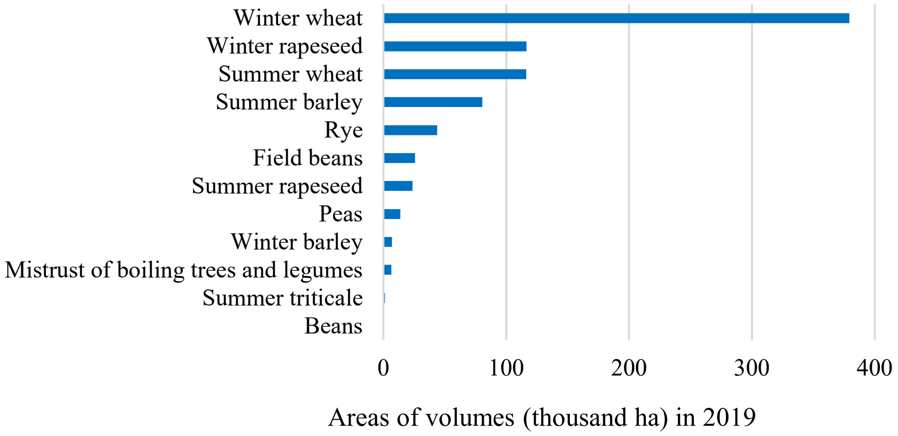

Figure 55. Use of sewage sludge in agricultural areas in 2019[44]

Advantages and disadvantages of the use of sewage sludge and its compost in agricultural land

Advantages	Disadvantages
Wastewater sludge and compost return into the soil a significant number of plant nutrients used for harvesting, particularly nitrogen, phosphorus and trace elements	Possible deterioration of certain soil, agricultural crops and water quality indicators
This is the cheapest way of using sewage sludge and its compost	Regular monitoring of the environmental situation is required
Sewage sludge and its compost can be incorporated into large areas	Competes with manure
The experience of EU Member States in this field can be widely exploited	Negative public attitudes could be encountered

Requirements for the quality of sewage sludge and its compost

Treated sewage sludge as well as compost prepared from treated or untreated sewage sludge may be used for soil manure in agricultural land; the mass concentration of heavy metals in its dry matter should not exceed the limited concentrations referred to in MK Regulation No. 362 (Table 24).

[44] http://data1.csb.gov.lv

Sewage sludge and its compost may be used for soil manure even if the concentration of not more than three heavy metals exceeds the concentration of the metals concerned by not more than 10 %.

The limit for mass concentration of heavy metals for soil manure and recultivation or disposal in municipal waste landfills and polygons for waste water sludge and its compost[45] has been determined.

> It is desirable to use sewage sludge and compost for the manure of agricultural land in which:
>
> - the concentration of especially toxic heavy metals, Cd, Pb, Hg, does not exceed that of Class 2;
> - organic matter content does not exceed 50 %;
> - a dry matter content is not less than 25 %.

In assessing the principles for the implementation of the circular economy for the use of sewage sludge and compost in agriculture, it is planned to extend and clarify the extent of agrochemical indicators and the form of expression so that it can be applied rationally to the development of a crop manure plan.

Requirements for soil quality prior to the incorporation of sewage sludge and its compost into soil

In accordance with MK Regulation No. 362, the following parameters must be determined in the average sample of the surface layer of soil before the incorporation of sewage sludge or its compost into agricultural land (Figure 56):

- an environmental reaction pH KCL must not be less than 5;
- mass concentration of heavy metals Cd, Cr, CU, Hg, Na, Pb and Zn;
- soil granulometric composition group.

[45] Cabinet Regulation No. 362, Regulations regarding the Use, Monitoring and Control of Wastewater Sludge and its Compost, Annex 9;

Figure 56. Incorporation of sewage sludge and compost into soil[46]

For the determination of the pH KCl of the soil environmental reaction, the last agronomic exploration materials of the soil may also be used if they are not older than five years.

The mass concentration of heavy metals in the soil prior to the incorporation of sludge and its compost must not exceed the limited concentrations referred to in MK Regulation No. 362 (Table 25).

The mass concentration of heavy metals in the soil shall be determined prior to the first integration of sewage sludge and its compost and shall be repeated before each subsequent incorporation of sewage sludge and its compost in the same area.

Where sewage sludge and its compost from WWTP with a load not exceeding 5000 CE are used for soil fertilising, the mass concentration of heavy metals in the soil should not be determined.

[46] www.civileats.com

Table 25

Limit of Mass Concentration of Heavy Metals in the Surface Layer of the Soil for the Incorporation of Sewage Sludge and its Compost (mg/kg)

No.	Heavy metals	phkcl 5–6		phkcl 6.1–7		phkcl > 7	
		sand, loam	clay, loam	sand, loam	clay, loam	sand, loam	loam, clay
1.	CD	0.50	0.60	0.60	0.70	0.80	0.90
2.	CR	40	50	60	70	80	90
3.	Cu	15	25	35	50	55	70
4.	Hg	0.10	0.20	0.25	0.35	0.40	0.50
5.	Ni	15	25	35	50	60	70
6.	WB	20	25	25	30	35	40
7.	Zn	50	65	70	80	90	100

Emission limit values and doses of sewage sludge and its compost fertiliser

Annual emission limit values for heavy metals, ammonia nitrogen and total phosphorus shall be the maximum mass of these substances, which may be incorporated on average per hectare per year with fertiliser for sewage sludge and its compost.

In terms of environmental protection and the supply of plant nutrients, the mass of nitrogen entered into the soil in the form of ammonium ($N\text{-}NH_4$) and nitrates ($N\text{-}NO_3$) is of great importance. These compounds are easily absorbed by plants, but their residues can leach from the soil and contaminate the waters. Therefore, in agricultural areas, the emission limit value for ammonia nitrogen ($N\text{-}NH_4$) is set in MK Regulation No. 362, at an average of 30 kg/ha^{-1} per year. If more than 12 months have elapsed after the production of a series of sewage sludge or compost, the amount of dry and ammonia nitrogen shall be determined again before the use of this series.

Since phosphorous compounds, unlike nitrogen, wash very little and are able to bind to the soil, the emission limit value for integrating sewage sludge and its compost is laid down in MK Regulation No. 362 for total phosphorus (P) – 40 kg/ha^{-1} per year.

Table 26

Annual Emission Limit Values for Heavy Metals in Agricultural Soils[47]

No.	Heavy metals	Average for a period of five years (g/ha/year)	
		sand, loam	loam, clay
1.	Cadmium (Cd)	30	35
2.	Chromium (Cr)	600	700
3.	Copper (Cu)	1000	1200
4.	Mercury (Hg)	8	10
5.	Nickel (Ni)	250	300
6.	Lead (Pb)	300	350
7.	Zinc (Zn)	5000	6000

[47] Cabinet Regulation No. 362, Regulations regarding the Use, Monitoring and Control of Wastewater Sludge and its Compost, Annex 10;

At one time, the maximum permissible dry matter dose of sewage sludge or its compost shall be calculated according to the annual emission limit values set out in Annexes 10 and 11 to MK Regulation No. 362 (Table 26), taking into account that the mass of such heavy metals may be incorporated into the soil at the same time with sewage sludge or compost (determined for each heavy metal separately), which does not exceed five-year emission limit values.

It is permitted to incorporate into the soil the smallest of the estimated doses of sewage sludge or its compost.

The dose of sludge and its compost at one time (dry weight) for sludge to be applied to the soil and its compost shall normally be expressed in t/ha^{-1}.

Manure for sewage sludge and its compost after dispersal on the field must be incorporated into the soil within three days, but must not be dispersed between 15 December and 1 March.

It is essential that the soil should not be overstretched with heavy metals and nitrogen and phosphorus compounds, thus regulating the mass of heavy metals and plant nutrients allowed to be incorporated into the soil at the same time (Table 27).

Table 27

Mass of Heavy Metals and Plant Feed Materials Allowed for Incorporation at One Application Time[48]

No.	Heavy metals	Permissible mass per application time, g/ha	
		sand, loam	loam, clay
1.	Cadmium (Cd)	150	175
2.	Chromium (Cr)	3000	3500
3.	Copper (Cu)	5000	6000
4.	Mercury (Hg)	40	50
5.	Nickel (Ni)	1250	1500
6.	Lead (Pb)	1500	1750
7.	Zinc (Zn)	25 000	30 000
		kg/ha	**kg/ha**
8.	$N\text{-}NH_4$	150	150
9.	P_{total}	200	200

Calculation of the dose of sewage sludge and its compost

In order to calculate the doses of sewage sludge or compost derived from it, which may be applied to the soil, the following information shall be required:

- emission limit values for heavy metals, ammonium nitrogen $N\text{-}NH_4$ and total phosphorus (P), taking into account the granulometric composition of the area concerned;
- the period of incorporation of sewage sludge and its compost in years, which is the period between two streams of sewage sludge;

[48] I. Gemste, A. Vucāns. "Sewage sludge", Jelgava: Agricultural University of Latvia, 2010, 276 p.

- concentration of heavy metals, ammonium nitrogen (or N) and P_{cop} in the dry matter of sewage sludge and its compost (data of the quality certificate for sewage sludge or its compost).

The calculation of the dose of sewage sludge and its compost is carried out as follows (the results of the calculation example are summarised in Table 28):

- the user of sewage sludge and its compost shall set the period of incorporation (in years) which may not exceed five years;
- the calculation of the maximum permissible mass of the individual heavy metals and plant feed elements in the soil, multiplying the relevant emission limit values and the number of years of incorporation;
- the pre-calculated mass values of each heavy metal, ammonia nitrogen and total phosphorus, divided by the concentration of these substances in one tonne of sewage sludge and its compost, shall be calculated for each indicator for the incorporation of the maximum permitted dry amount of sewage sludge and its compost into the soil;
- the minimum amount of dry matter calculated for soil application;
- for incorporation into the soil, the maximum permitted dose of naturally wet sewage sludge or compost fertiliser shall be calculated according to the following formula:

$$N = \frac{100 \times d}{e}, \qquad (5)$$

where

N – the maximum permitted dose of naturally wet sewage sludge and its compost, t/ha;
d – the maximum permitted dry matter dose of sewage sludge and its compost, t/ha for the soil;
e – dry matter content of sewage sludge and its compost prior to incorporation in soil, %.

Table 28

Example of Calculation of the Dry Matter Dose of Wastewater Sludge and its Compost for Agricultural Land

I	II	III	IV	V
Results reported in the test report *		Annual emission limit values * *	Maximum permissible mass for incorporation * * *	Maximum dose of dry matter for incorporation * * * *
Substance	Concentration			
Heavy metals	mg/kg or g/t	g/ha	g/ha	t/ha
Cadmium (Cd)	2	30	150	75
Chromium (Cr)	90	600	3000	33
Copper (Cu)	150	1000	5000	33
Mercury (Hg)	1.5	8	40	27
Nickel (Ni)	30	250	1250	42
Lead (Pb)	100	300	1500	15
Zinc (Zn)	1000	5000	25000	25
Plant feed materials	g/kg or kg/t	kg/ha	kg/ha	t/ha
N_{group}	40	-	-	-
$N\text{-}NH_4$ * * * * * *	5 * * * * * *	30	150	30
P_{total}	15	40	200	13 * * * * * * *

* The results reported in the test report have been accepted.

* * Data according to the annual emission limit values for heavy metals in agricultural soils (Table 26), assuming the soil type is sand, loam.

* * * On the assumption that the number of years of the incorporation period is five years, Column III * 5 years.

* * * * The breakdown of the maximum permissible mass of the sample with the concentrations reported in the test results.

* * * * * If the concentration of ammonia nitrogen in sludge has not been determined in a laboratory, calculated by correcting the concentration of N_{cop} with the corresponding factor of 0.12.

* * * * * * Calculated (40 × 0.12 = 5 g/kg).

* * * * * * * The maximum permitted dry matter dose of sewage sludge and its compost, i.e. the smallest of all calculated.

According to the sample calculated in Table 28, the maximum permitted dry matter dose of sewage sludge and its compost 13 *t/ha* and assuming a dry content of the sludge fertiliser is 25 %, the maximum permitted dose of naturally wet sewage sludge and its compost may be calculated for the incorporation:

$$N = \frac{100 \times 13\ \text{t/ha}}{25\ \%} = 52\ \text{t/ha}$$

Before calculating the dose of sludge and its compost, account should be taken of:

concentration of heavy metals – mg/kg = g/t;

total phosphorus concentration in dry matter – g/kg = **kg/t;**

total nitrogen concentration in dry matter – g/kg = **kg/t;**

If the concentration of N and P in sludge and the dry matter of its compost is reported in %, this indicator shall be multiplied by ten, converted to g/kg **or kg/t.**

For the incorporation of sewage sludge of Class 1 and 2 and their compost, the maximum permissible dry matter dose shall be calculated only on the basis of emission limit values for ammonia nitrogen and total phosphorus, as in this case heavy metals do not break the sludge and its compost doses.

The dose of naturally dispersed wet sewage sludge with acceptable precision may be determined by vehicle volume, taking into account that the approximate mass of m^3 naturally wet sewage sludge is:

- with a dry matter content of up to 5% – 0.95 t
- with a dry matter content of 5–20 % – 0.90 t
- with a dry matter content exceeding 20 % – 0.85 t

Documents required to certify the dose used

For the incorporation into the soil, the manufacturer of wastewater sludge and its compost dry matter shall calculate the amount of waste water sludge and its compost. This indicator shall be recorded in a statement, which is a written document on the use of sewage sludge and its compost, to be drawn up together by the producer of sewage sludge and its compost and the user.

The certificate shall be drawn up on the basis of the following documents, which shall be annexed:

- a copy of the quality certificate for sewage sludge and its compost series;
- the results of the exploration of surface soils;
- cartographic material (on a scale of 1:10 000 or 1:5000) with earmarked areas for the incorporation of sewage sludge fertiliser.

In the mapped contour, the year of incorporation of sewage sludge and its compost and the dry matter dose shall be recorded.

If the sewage sludge or compost is re-incorporated into the area concerned, the attestation shall only be accompanied by a copy of the quality certificate for the wastewater sludge or the compost series.

The attestation shall indicate:

- the amount of sewage sludge or compost;
- the area intended for soil cultivation;
- the maximum permitted dose of dry matter and naturally wet sewage sludge or compost;
- agricultural crops to be cultivated during the first year following the incorporation of sewage sludge or compost.

Each declaration shall be numbered and registered by the producer of sewage sludge or compost in a special register. It shall be maintained and stored by the producer of sewage sludge or compost. The original of the certificates and the registration journal shall be kept for a period of not less than ten years when it is completed.

Selection of areas

The use of sewage sludge and its compost in areas utilised for soil manure is related to the restrictions specified in regulatory enactments. Their aim is to minimise the release of pollutants contained in this fertiliser to all environmental components, as well as the release of nitrogen and phosphorus to water, so as not to increase the concentration of heavy metals in crop yields and to limit or completely exclude the penetration of pathogenic micro-organisms.

According to MK Regulation No. 362, sludge and its compost must not be dispersed and incorporated in the following locations:

- slopes with a slope greater than 7°;
- frozen or snow-covered soil;
- flooding and flood-threatened areas;
- closer than 100 m from the individual water-taking sites;
- closer than 100 m from residential buildings, food processing and food marketing plants;
- closer than 50 m from the coastline of the water body or watercourse;
- in places where it is prohibited in accordance with the regulatory enactments regarding protection zones.

If agricultural areas are located in specially protected nature areas, the use of sewage sludge and compost shall be coordinated with the regional environmental board.

It is desirable to incorporate sewage sludge and its compost:

1) in soils of heavier granulometric composition (loam, clay), to minimise the leaching of plant nutrients (especially nitrogen) embedded with sewage sludge and its compost);
2) in areas with low mobile phosphorus content (P_2O_5 < 70 mg/kg, P<30 mg/kg), it should also be noted that potassium fertilisers should be incorporated into low-moving soils because there is very little potassium in sewage sludge and its compost;
3) recovery of closed agricultural areas; correction of areas where it is appropriate to combine sewage sludge and its compost with cross-winter greening manure (oil plants, redwood, etc.).

Crop selection

According to MK Regulation No. 362, sewage sludge and compost **must not be used:**

- for the cultivation of vegetables and berries in covered areas;
- for the rearing of potatoes, vegetables and berries in an open field of less than 0.10 ha;
- in the case of surface manure and line manure during the growing season for food and feed crops;

- in the case of surface manure in pasture during the year of use thereof, except in the case of the renewal of the gilt, the repluring of the soil, and the sewage sludge and the compost thereof shall be incorporated into the soil.

The period between the incorporation of sewage sludge and compost into the soil and the harvesting of agricultural crops must be not less than:

- ten months, when growing fruit and berries in the open field, as well as rootcrops, potatoes and vegetables in direct contact with the soil;
- three months, when growing other agricultural crops, with the exception of perennial grasslands used for mowing or grazing.

In areas of perennial grassland used for mowing or grazing, sewage sludge or compost shall be dispersed after the last hay has been collected or grazed during the growing season.

In selecting crop species to be cultivated in areas where sewage sludge and its compost is incorporated, it is recommended to take into account biological characteristics of crop species such as their ability to use large amounts of wastewater sludge and plant nutrient elements (nitrogen, phosphorus) in its compost and less to absorb heavy metals.

In Latvia so far, there are relatively few observations of the type of crop species that would be desirable to grow in areas where sewage sludge and its compost is embedded. However, on the basis of relatively small results in Latvia and foreign experience, it can be concluded that changes in the concentration of harmful substances in cereals are very small and do not compromise the quality of cereals themselves or products produced from them. The recommended crops to be cultivated after the incorporation of sewage sludge and its compost into the soil are cereals, grasses, maize, crucifixion fertilisers, and rapeseed for harvesting and technical purposes (mainly for the production of biofuels).

The changes in concentrations of heavy metals found in vegetables and bumpers are higher and are more commonly used as heat-free. Thermal treatment would ensure the death of micro-organisms present in the fertiliser, therefore it is not recommended to use sewage sludge and its recycling products in the fertilising of these crops.

In order to make more efficient use of the significant quantities of nitrogen and phosphorus embedded in the soil of sewage sludge and itsr compost, the following plant conversion regime could be implemented in the first years after the incorporation of sewage sludge and its compost:

- Year 1: Barley for fodder or seed and grasses;
- Year 2: Grasses for hay or grazing;
- Year 3: Grasses for hay or grazing.

The most efficiently and environmentally safely sewage sludge and its compost may be used on the basis of a crop manure plan developed in accordance with Cabinet Regulation No. 834 of 23 December 2014, "Requirements for the Protection of Water, Soil and Air from Pollution caused by Agricultural Activities", Annex 4 "Summary of crop-fertilising plans".

In order to ensure the protection of water and soil from nitrates pollution caused by agricultural activity, it is necessary to take into account the requirements laid down in Cabinet Regulation No. 834 of 23 December 2014, "Requirements for the Protection of Water, Soil and

Air from Pollution caused by Agricultural Activities” regarding the maximum permitted nitrogen limits for crops (Table 29).

Table 29

Maximum Nitrogen Limits for Different Crops (kg N/ha) *

	Yield level, t/ha			
Crop	**<3.0**	**3–5**	**5–7**	**>7.0**
Rye (130)	65	95	130	160
Winter barley (150)	75	105	140	185
Winter triticale (140)	75	105	140	200
Summer barley (150)	65	100	135	170
Oats (110)	60	90	120	–
	<2.0	**2.0–4.0**	**4.,0–5.0**	**>5.0**
Winter rapeseed	90	150	190	230
	<2.0	**2.0–3.0**	**3.0–4.0**	**>4.0**
Summer rapeseed	90	120	160	200
	<40	**40–60**	**>60**	
Corn, green pulp	110	160	200	
Fodder beets, sugar beets	90	150	190	
	<4.0	**4.0–8.0**	**>8.0**	
Grasses in arable land and meadow, hay	80	120	170	
	<20	**20–30**	**>30**	
Pastures, green pulp	100	155	240	

* In soils with a level of organic matter of more than 30 % in the 0–30 cm layer, the amount given in the table should be multiplied by a factor of 0.7 when setting maximum levels.

The EU Council Directive on the protection of waters from pollution caused by nitrates of agricultural origin (91/676/EEC) provides that the annual amount of manure embedded in the land per unit of the farm or herd, including the animals themselves, must not exceed the determined quantity per hectare of fertilisers containing 170 kg N. The Directive allows that requirement should also be extended to the incorporation of wastewater sludge and its compost into the soil.

4.5.2. Use of sewage sludge and its compost for greening

Greening is generally understood as the placement of multiannual ornamental lawns, trees, bushes and flower plantations in living and recreational areas, sports complexes, outskirts of transport grids, etc. In general, areas to be greened are low-fertile soils or even bare soil. In order to create a good lawn and ensure adequate growth conditions for trees, shrubs and flowers, these areas need to optimise the response of the soil (bottom) with a significant amount of organic matter and plant feed materials to be incorporated into it. Sewage sludge and its compost can be used successfully for these purposes.

In accordance with MK Regulation No. 362, in when greening areas:

- sewage sludge and compost may be used where, in the dry matter, the concentration of heavy metals does not exceed those corresponding to Class 2;
- annual wastewater sludge with a dry matter content of at least 25 % and without an unpleasant odour may be used;
- at the same time, only the mass of heavy metals not exceeding the seven-year emission limit values may be incorporated into the soil with sewage sludge or compost.

Advantages and Disadvantages of the Use of Sewage Sludge and its Compost in Greening

Advantages	Disadvantages
Re-use of organic substances and plant feed materials	There is a risk that in certain cases humans and animals may directly absorb particles of sewage sludge or its compost-fertilised soil
Noticeably higher doses of sludge and its compost may be introduced compared to agricultural areas, as there is no risk of contamination of foodstuffs	Increased quality requirements for sewage sludge and its compost
Integrated sewage sludge and its compost have a significantly longer effect than fertiliser	Recycled sewage sludge should be used preferably
Low cost	Could cause negative attitude of society
May also be used in areas less than 0.1 ha (small home gardens)	The intensively growing lawn in the fertilised area requires more frequent watering and mowing

Emission limit values and calculation of the amount of manure for sewage sludge and its compost

The annual emission limit value for metals embedded in the soil of sewage sludge and its compost fertilizers may be increased to 50 % in accordance with MK Regulation No. 362; their absolute values and the calculation of the maximum permissible dry dose, assuming that the fertiliser is embedded in mould soil and its dry matter content is 27 %, as summarised in Table 30.

Table 30

Maximum Permissible Mass of Sewage Sludge and Dry Matter of its Compost for Incorporation into the Soil for Greening (example of calculation)

I	II	III	IV	V
Heavy metals	**Emission limit values, g/ha/year ***	**Maximum permissible mass for incorporation, g/ha * ***	**Concentrations in dry matter mg/kg of sewage sludge and its compost (g/t) * * ***	**Maximum permissible dry matter dose t/ha * * * * ***
	sand, sand	**sand, sand**		
CD	45	315	2	157
CR	900	6300	90	70
Cu	1500	10500	150	70
Hg	12	84	1.5	56
Ni	375	2625	30	87
WB	450	3150	100	31 * * * * *
Zn	7500	52500	750	70

* Data according to the annual emission limit values for heavy metals in agricultural soils (Table 26), assuming that the soil type is sand, loam, and increasing the emission limit value by 50 %.
* * In line with the permissible maximum period for the incorporation of heavy metals into the soil in the case of greening, for the – period of 7 years, Column II * 7 years.
* * * The results reported in the test report and in the Sludge Compost Series Quality Certificate have been accepted.
* * * * Division of the maximum permissible mass for the soil with the concentrations reported in the test results.
* * * * * The maximum permitted dry matter dose of sewage sludge and its compost, i.e. the smallest of all calculated.

As calculated in Table 30, the maximum permissible dry-matter dose of sewage sludge and its compost of 13 t/ha, which may be incorporated into the soil and assuming a dry-state content of 25 % of the sludge fertiliser, may be calculated for the incorporation into the soil at the maximum permitted dose of naturally wet sewage sludge and its compost:

$$N = \frac{100 \times 31\ \mathrm{t/ha}}{27\ \%} = 115\ \mathrm{t/ha\ jeb\ 11{,}5\ kg/m^2}$$

> Sewage sludge used for greening sites shall be incorporated into the soil within 24 hours of dispersal.

When incorporating sewage sludge and its compost into the soil, it must be noted that:

- it is advisable to introduce potassium fertilisers in conjunction with sewage sludge and its compost;
- sewage sludge and its compost are best incorporated shallow with a cutter, but in small areas with a hoe or an iron rake.

The mixture of grass seeds is of great importance in creating a decorative lawn. Relatively simple but universal is the following mixture of medicinal products (% of total seed mass): red ause – 70–75 %, meadow's scarlet – 20–25 %, perennial airliner – 5–10 %. The building of a good lawn is largely ensured by:

- volume of the mixture of medicinal products 30–40 g/m^2;
- the lawn must be sown by 15 August;
- the seed of the medicinal product must be placed at a depth of 2–3 cm and must be applied firmly after incorporation;
- the first mowing should be done after 3–4 weeks of sowing.

Where sewage sludge and its compost are used for manure of ornamental shrubs and flowers, consultating with specialists in the sector concerned shall be obtained.

Documents required for the dose statement

If the producer of sewage sludge or compost and the user of this fertiliser agree on the use of sewage sludge or compost for greening, they shall draw up a written declaration on the basis of the following documents, which shall be attached as an Annex:

- a copy of the quality certificate for the wastewater sludge or compost series;
- cartographic material of the area concerned (on a scale of 1:500 or 1:1000) with earmarked areas in which sewage sludge or compost is intended to be incorporated.

The attestation shall indicate:

- the amount of sewage sludge or compost;
- the area intended for soil cultivation;
- maximum amount of dry and naturally wet sewage sludge or compost to be incorporated into the soil.

Each declaration shall be numbered and registered by the producer of sewage sludge or compost in a special register. The registration journal shall be maintained and stored by the producer of sewage sludge or compost. The original certificates and the registration journal shall be kept for a period of not less than ten years when completed.

4.5.3. Use of sewage sludge and its compost for the cultivation of willows

Willows is one of the types of agricultural energy crops. In these plantations, energy is derived from wood chips and is also used for pulp extraction at experimental levels. Willow plantations are one of those renewable energy technologies that have commercialised and gained their market niche.

Willows are a fast-growing culture and attract a lot of nitrogen and phosphorus from the soil. They are not bred for the production of foods, so sewage sludge and its compost can be used to fertilize them. Due to the intensive uptake of heavy metals from soil, including cadmium, contaminated soil can be recovered in these areas.

The use of sewage sludge for the fertilising of plantation will reduce the risks of hygiene and heavy metal pollution associated with the use of sewage sludge. The willows are burned and all surviving pathogens are killed. The heavily growing plantations from the soil capture heavy metals brought in with sewage sludge, which are released into the ash after combustion.

Advantages and disadvantages of using sewage sludge and its compost for the cultivation of willows

Advantages	Disadvantages
Lower risk of spreading infections and contamination of food products	High costs of planting in the year of installation
All surviving pathogens die by burning willows	Risk of environmental pollution using excessive doses of sewage sludge
Production cycle to be fully mechanised	
Lower costs than using sludge in forestry	
Extensive use of plantations in non-agricultural areas	
Renewable energy resource – wood	
Increasing biodiversity in agricultural areas	

Emission limit values and doses of sewage sludge and its compost fertiliser

In Latvia no regulatory framework has been developed for the use of sewage sludge for the fertiliser of energy crops. When growing willow plantations on agricultural land, the conditions of MK Regulation No. 362 relating to the fertilising of agricultural crops should be taken into account.

The dose of fertiliser shall be determined according to the following conditions:

Sludge and its compost are used for the fertilising of plantations	⇨	Based on the concentration of ammonium nitrogen, total phosphorus and heavy metals in sludge and its compost, as well as the emission limit values for
Sludge and compost thereof shall be used in plantations fitted in the area to be recovered	⇨	On the basis of the conditions for recultivation of degraded areas. The maximum permissible dose depends on the quality class of sludge and its compost and the granulometric composition of the soil

A growing willow plantation consumes 60–100 kg of nitrogen (N), 10–15 kg of phosphorus (P) and 35–50 kg of potassium (K) per 1 ha per year. The recommended dose of fertiliser per 1 ha per year is 100–200 kg N, 20–40 kg P and 100–200 kg K. The year dose of N per plantation may be reduced to 60 kg/ha or no fertiliser should be given at all. The fertiliser shall be re-introduced after the cutting of willows by incorporating a 3–5-year dose.

The observations made in 2009 focused more on the impact of sewage sludge manure on changes of quality indicators of key environmental components through the use of a wastewater sludge fertiliser in the willow plantations. It was found that[49]:

- the concentration of heavy metals in the surface of mineral soils and peat soils increased by 14 %, which does not exceed the limited concentration;
- the concentration of heavy metals in wood increased by only 4–8 % compared to the control option;
- No increased concentrations of heavy metals in surface waters were identified.

Management of plantations and use of willows

The use of a plantation can continue for 20–30 years. On average, 7–10 tonnes of wood dry matter per year (20–40 tight cubic metres) are produced from a hectare in the willow plantation. When mowing every four years (Figure 59), 28–40 tonnes of wood dry matter (80–160 tight cubic metres) is obtained. In the best plantations, the increase in biomass is up to 12 tonnes of dry matter per year. In Sweden, for example, farmers' revenues from the disposal of chips for heating companies is equivalent to those for wheat.

Figure 59. Mowing of willows[50]

It is possible to use the crop in several ways:

1) For heating. Wood chips are used in district heating water heaters and steam boilers suitable for the incineration of harvesting residues or are processed into wood granules, which are also used in the heating of private houses. The chips are as high quality and give the same heat as the chips from other leaves. The use of layers in heating does not increase the emissions of carbon compounds or other greenhouse gases into the atmosphere, by burning plants, by releasing as much carbon as is assimilated through photosynthesis.

[49] D. Lazdiņa.(2009) Opportunities for the use of sewage sludge in willow plantation. Summary of promotion work for obtaining *a scientific degree in* the forest science sector. Jelgava.
[50] www.farmersjournal.ie

2) For fertilising of plantations. Willow ash may be used for the fertilising of plantations, feeding the soil with potassium in sewage sludge.
3) In craftsmanship. Willows are known as a raw material for a wide variety of weavings, ranging from simple mushroom baskets to room and garden furniture.
4) In medicinal products. Medical properties of willows are also used in beauty industry. Their leaves and bark contain glycosides characterised by anti-inflammatory, painkiller, and temperature-lowering effects.

4.5.4. Use of sewage sludge and its compost in forestry

In Latvia, dry sandy soil, forest burns, as well as areas unfit and unused for agricultural purposes, whose afforestation requires large capital investments, are the most likely areas of use of wastewater sludge in forestry. This is particularly the case for dry forest soils with little humus and nutrients. In these areas, planting of different crops requires additional measures, including additives of organic substances and minerals.

Advantages and disadvantages of the use of sewage sludge and their compost in forestry

Advantages	Disadvantages
Re-use of organic substances and plant feed materials	Soil contamination and consequently impacts on flora, fauna, groundwater and surface water reservoirs are difficult to predict
Fertilizer increases forest productivity	No intensive manure of forest soils is required
Minimum risk to human and animal health	Monitoring of the environmental situation
Low cost	Debatable usage type
	Requirements of the Forest Steward Council (FSC) for forest certification

Requirements for the use of sewage sludge and its compost fertiliser

In Latvia, the use of sewage sludge in forestry is governed by MK Regulation No. 362. Only treated sewage sludge and compost shall be used for soil improvement and fertilising in forestry, which has the mass concentration of heavy metals in the dry matter does not exceed the concentration limit referred to in Annex 9 to MK Regulation No. 362.

It is permitted to use treated sewage sludge and compost in plantation forests, but only compost is allowed in afforestation of smolders, degraded forest soils and forest burns. Soil exploration prior to the incorporation of sewage sludge or compost is not necessary.

For the characterisation of the quality of each wastewater sludge and its compost series, the dry matter content and mass concentration of heavy metals shall be determined in accordance with Annex 2 to MK Regulation No. 362.

The mass of heavy metals (determined separately for each heavy metal) may be incorporated into the soil at the same time when sewage sludge or compost, which does not exceed the five-year emission limit values.

International experience and forest management standards require that the use of sewage sludge in natural forests is not allowed, but the use of sewage sludge in plantation forests, including Christmas tree plantations, as well as the rehabilitation of the forest with nutrients in poor and scruffy soils is possible. In such a case, the use of wastewater sludge extraction technology – deep welling, which means that smothering is not allowed.

Forest soils are characterised by a neutral to acid response. Heavy metals present in such soils are more active and therefore are more extensive in the deeper layers of soil. There is a lot of nitrogen in sewage sludge and the trees are unable to use it completely, so sewage sludge fertiliser contributes to nitrification processes and the leaching of nutrients (nitrogen, potassium, calcium, magnesium) from the surface soil horizons, but a small dose of sewage sludge (up to 10 tonnes of dry matter per ha per year) incorporated into the soil does not normally present this problem because the residual nitrogen is used by undercover vegetation. In wet soils, the amount of sewage sludge fertiliser should be reduced approximately twice.

A high dose of sewage sludge fertiliser can contribute to the decay of the soil's tremulous horizon and to the washing of nitrogen into groundwater, as well as to significantly changing natural habitats. Therefore, it is not recommended to use sewage sludge fertiliser in adult forest stands but for forest renewal as a buffer for starting fertilizers and organic matter.

In addition, potassium-containing fertilisers should be provided when using sewage sludge fertiliser, particularly if high levels of fertiliser are used. The best and cheapest potassium fertiliser for the forest, which also provides a reserve for trace elements and increases soil pH at the same time, is wood ash.

Required documents

Latvia operates a number of forest certification systems, such as PEFC and FSC. The PEFC provides more economic benefits and represents the interests of forest industry, while the FSC's certification includes reinforced environmental requirements for forest management. The majority of Latvian forest owners, including JSC "Latvijas Valsts meži", use the FSC certification system. In accordance with the rules of the PEFC certification, fertilisers, including wastewater sludge compost, may be used in the forest. The FSC's certification rules do not allow the use of fertilisers in forest stands.

If the producer of sewage sludge or compost and the user of this fertiliser agree on the use of sewage sludge or compost for soil manure in forestry, they shall draw up a written statement on the basis of the following documents:

- a copy of the quality certificate of the wastewater sludge or compost series;
- cartographic materials (on a scale of 1:10 000 or 1:50 00) with earmarked areas intended for incorporation of sewage sludge or compost.

The attestation shall indicate:

- the use of sewage sludge or compost;
- the amount of sewage sludge or compost;
- the area intended for incorporation;
- the maximum permitted dose of dry matter and naturally wet sewage sludge or compost for incorporation.

If the area intended to be fertilised with sewage sludge or compost is located in a specially protected nature area, the requirements referred to in Paragraph 40 of the MK Regulation No. 362 shall be complied with.

The producer of sewage sludge or compost shall, prior to the incorporation of sewage sludge or compost into the soil, ensure the calculation of the maximum permitted dose of naturally humid sewage sludge and compost for incorporation and shall notify the user of that fertiliser.

Each declaration shall be numbered and registered by the sewage sludge producer or compost manufacturer in a special journal maintained and stored in accordance with Paragraph 36 of MK Regulation No. 362.

4.5.5. For recultivation of sewage sludge and its degraded areas

Degraded areas are areas with ruined soil covers resulting from the extraction of clay, sand, gravel and other mineral resources by open method (quarry) (Figure 560), land works in construction, as well as other works related to the destruction of soil blankets. Recultivation is a complex of meliorative, cultural and agrotechnical measures to restore soil covers of degraded areas.

Figure 560. Moulded peat bog[51]

[51] A. Priede A. Silamiķele. 2015. Recommendations for re-naturisation of peat bogs. Biology Institute of the University of Latvia, Salaspils.

Advantages and disadvantages of the use of sewage sludge and its compost for the recultivation of degraded areas

Advantages	Disadvantages
Re-use of organic substances and plant feed materials	Local site contamination
Pollutants are excluded from the human food or animal feed chain	Risk of groundwater contamination
Relatively low costs	Monitoring of the environmental situation
Large doses of sewage sludge and its compost can be used in small areas, reducing transportation and incorporation costs.	

Requirements for the use of sewage sludge and its compost fertiliser

In Latvia, the use of sewage sludge for recultivation of degraded areas is governed by MK Regulation No. 362. It is permitted to use treated sewage sludge or compost for the recuperation of degraded areas for which the mass concentration of heavy metals in the dry matter does not exceed the concentration limit referred to in Annex 9 to MK Regulation No. 362.

Before applying sewage sludge or compost to the area concerned, the manager of degraded areas shall determine the granulometric composition group of the top 25 cm thick layer and the soil environmental reaction pH KCl.

Sewage sludge or compost for the recultivation of degraded areas must not be used if:

- the ground surface layer response rate pH KCl is less than 5.0;
- the area to be recovered is be permanently or temporarily flooded.

For the recultivation of degraded areas, dry matter doses of sewage sludge or compost may be used, which do not exceed the dose limits referred to in Annex 12 to MK Regulation No. 362 (Table 31).

Table 31

Limit of Dry Matter for Wastewater Sludge and its Compost for Recultivation of Degraded Areas (t/ha)

No.	Sludge class	Gravel, sand, loam	Loam, clay
1.	I	250	350
2.	II	140	200
3.	III	90	130
4.	IV	60	90

If at least 5 cm thick peat layer has remained in the developed peat quarry prior to the incorporation of sewage sludge or compost, the environmental response pH KCl shall be determined separately for the remaining peat layer and under its existing mineral pulp, while the granulometric composition group shall be determined only for mineral pulp.

Dispersed sewage sludge should preferably be integrated into the top layer of the bottom. Following the incorporation of sewage sludge into the area to be recovered, a suitable mixture of medicinal products must be sown by 15 August at the latest. The newly constructed lawn must be mowed at least twice a year, leaving the mass of medicine there.

The degraded areas shall be recuperated, by once incorporating significantly higher doses of sewage sludge into the soil compared to soil manure in agricultural lands. The size of the doses of sewage sludge depends on the objectives of recultivation. In the case of recultivation to enrich soil with plant nutrient elements, 50–100 t/ha of wastewater sludge and its compost dry matter is normally incorporated, but if the objective is to increase the organic matter content, 100–500 t/ha of sewage sludge and its compost dry matter should be incorporated.

Documents necessary for drawing up a recultivation plan

Sewage sludge and compost in the recultivation of degraded areas shall be used according to **a recuperation project** specially designed for the area in question, in which, in addition to other indicators, information on:

- the granulometric composition and environmental response of the surface layer of the degraded area;
- hydrogeological exploration of degraded area (bottom lithological characterisation for aeration zone and water retention layer, groundwater flow direction, groundwater consumers within a radius of 0.5 km).

If the producer of sewage sludge or compost and the manager of degraded areas agree on the use of sewage sludge or compost for the recultivation of degraded areas, they shall draw up a written statement on the basis of a site recultivation project and a copy of the wastewater sludge quality certificate or the compost quality certificate.

The attestation shall indicate:

- the amount of sewage sludge or compost;
- the area intended for incorporation;
- the maximum permitted dose of dry matter and naturally wet sewage sludge or compost for incorporation.

The producer of sewage sludge or compost shall, prior to the calculation of the sewage sludge or compost, calculate the maximum permitted dose of naturally wet sewage sludge or compost and notify the operator of the degraded areas thereof.

Each statement shall be numbered and registered by the producer of sewage sludge or compost in a special journal maintained and stored in accordance with Paragraph 36 of MK Regulation No. 362.

4.5.6. Use of treated sewage sludge and its compost for recultivation of landfill sites and disposal in waste management polygons and landfill sites

In accordance with MK Regulation No. 362, it is possible to dispose of treated sewage sludge and sewage sludge compost in landfill sites. At the time of development of the handbook, there are ten waste management landfills in Latvia, of which the amount of waste imported is less than initially forecast.

The EU has set the objective of recovering resources from waste, and discussions are ongoing on the possibility of the EU banning completely the disposal of waste that is recyclable, including sewage sludge, in the foreseeable future.

Therefore, the disposal of sewage sludge in landfill is not considered to be possible in the long term, except where sewage sludge or compost thereof, where the concentration of heavy metals corresponds to Class 5, and in accordance with MK Regulation No. 362, they are to be disposed of only at the landfill site of hazardous waste.

Compost of sewage sludge (except sewage sludge of Class 5) may be used for the recuperation (flip-flop) of landfill sites and landfill sites after the total or partial closure of a waste polygon or landfill in accordance with the regulatory enactments regarding waste management. In accordance with Cabinet Regulation No. 1032, "Regulations Regarding the Construction, Close and Recultivation of Waste Landfills and Waste Polygons", in order to ensure the inclusion of a closed landfill or polygon in the landscape and the continued utilisation of the site, the landfill or dump operator shall ensure the development of a landfill or landfill rectification project. It shall, in addition to other measures, provide for the establishment of a landfill site with the upper layer of at least 0.2 m thick soil. This layer may be composed of wastewater sludge compost in waste dumps and landfills of all classes (1–3). The covering layer is designed to accumulate rainfall waters by preventing erosion and ensuring good conditions for grass growth.

Advantages and main disadvantages for the disposal of sewage sludge in municipal waste landfills

Advantages	Disadvantages
Partial energy recovery by collecting biogas and using it for the production of heat or electricity	If biogas is not collected, it enters the atmosphere and contributes to negative climate change, while volatile organic pollutants have a negative impact on human health
Exclusion of pollutants from circulation	Excludes organic matter and plant feed materials
Lower costs compared to incineration of sewage sludge	There is a risk that filtering waters, if not collected or processed, may contaminate soil and groundwater

4.5.7. Incineration of sewage sludge

Sewage sludge is not burned in Latvia. Also, MK Regulation No. 362 does not include requirements for the operation of sewage sludge incineration plants and for the quality of their final products.

The incineration of municipal waste in Latvia is governed by MK Regulation No. 323 "Requirements for the incineration of waste and the operation of waste incineration plants".

The main advantage of combustion is complete oxidation of organic substances. Ash from incineration is an inert material and does not exceed 25 % of the original wastewater sludge dry matter. The technology (Figure 59) is suitable for the elimination of polluted (most commonly industrial sewage sludge), biologically difficult-to-break sewage sludge, which cannot be otherwise used.

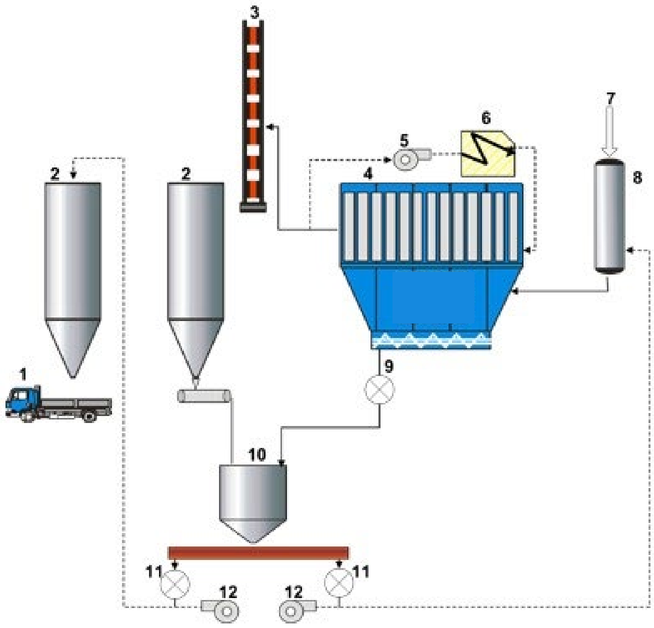

Figure 561. Principle scheme of the incinerator for sewage sludge[53]

1 – loading of sludge; 2 – elevator; 3 – chimney; 4 – filter with reactor; 5 – air circulation fan; 6 – furnace register; 7 – heat exchanger; 8 – reactor; 9 – ash discharge; 10 – storage container; 11 – air supply shutter; 12 – blower.

Depending on the content of organic substances in sewage sludge, the concentration of nutrients after incineration is approximately twice higher than before. The calculated phosphorus content of monoincinerated sewage sludge is between 8 % and 20 %. Organic micro-pollutants are destroyed by burning, but mercury is removed from the smoke gas purification equipment. Unfortunately, the concentration of all other heavy metals is increasing as a result of combustion, preventing the use of ash as a direct fertiliser. Metals can be separated by acids or ionbordering equipment and reused. Heavy metals in ash are in the form of poorly soluble compounds, but severe metal leaching may occur in acidic or anaerobic environments.

In Europe, the incineration of sewage sludge is used only in large WWTPs (Figure 60), where the load corresponds to several million CE or industrial sewage sludge which is not otherwise usable.

Figure 62. Wastewater sludge-burning plant in the canton of Zurich, Switzerland[52]

Advantages and main disadvantages of incineration of sewage sludge

Advantages	Disadvantages
The handling and storage of incineration and waste products does not spread an unpleasant smell	Excludes organic matter and plant feed materials from circulation, ash usually contains too many heavy metals to be used in agriculture for fertiliser
All pathogens in sewage sludge die	This leads to greenhouse gases
Exclusion of pollutants from circulation	High costs, to be used only in large WWTPs
Produce energy that can be used both for the maintenance of the process and for the use in heating systems	The operation of wastewater sludge incineration equipment depends heavily on the stability of the supply of sewage sludge
The ash obtained is inert and, when properly managed, does not cause environmental pollution	The combined waste incineration system will reduce the return on fuel heat and increase costs due to the installation of additional air treatment equipment

4.5.8. Monitoring of the environment for the use of sewage sludge and its compost, quality control and records on use

According to MK Regulation No. 362, the Latvian Environment, Geology and Meteorology Agency shall perform environmental monitoring of the use of sewage sludge and compost in areas to be utilised for agriculture in accordance with the National Environment Monitoring Programme.

Quality control

The procedures for the quality control of sewage sludge and its compost shall be determined by MK Regulation No. 362. The determination of the quality of sludge and its compost shall be ensured by the producer of sewage sludge and the compost manufacturer.

The determination of the quality of sewage sludge and its compost shall include:

[52] www.mogroup.com

- sampling and preparation for testing;
- testing of samples in a laboratory accredited for the determination of the relevant indicators;
- evaluation of test results;
- drawing up of a quality certificate and its registration in a special journal;
- compilation and submission of the results of the year of quality determination to the VVD.

The quality of sewage sludge or its compost shall be determined for each series.

The wastewater **sludge series** is the mass of sludge with a uniform chemical composition, similar physical and other characteristics.

The quality of each series of sewage sludge is characterised by an average sample, the procedures for the formation of which are shown in Table 32.

The compost series shall mean the mass of compost composed of sewage sludge and vegetable filling materials and not exceeding 1000 tonnes at the beginning of composting.

For the determination of the quality of the compost series, a single average sample consisting of at least 25 individual samples shall be produced.

Table 32

Intermediate Sample of Sewage Sludge in Treatment Plants[53]

No.	Load CE of wastewater treatment plants	Average number of samples per year	Average sampling period (months)	Periodicity of individual sampling	Number of samples to be tested per year		
					for the detection of heavy metals *	for the determination of agro-mic indicators	for the determination of the dry matter content * *
1.	<2000	1	12	2 times a month	1 * * *	1	2
2.	2001–5000	1	12	2 times a month	1 * * *	1	4
3.	5001–10000	2	6	3 times a month	2	1	6
4.	10001–50000	3	4	once a week	3	2	12
5.	50001–100000	4	3	every three days	4	3	24
6.	>100000	12	1	every day	12	4	52

* If, during the last two years in all wastewater sludge series the concentration of certain heavy metals has not exceeded the values corresponding to Category 1, the testing to detect these metals may be carried out twice, but not less frequently than once a year.

* * The dry matter content in individual samples shall be determined immediately after their collection.

* * * If only municipal wastewater is treated in a treatment plant, the mass concentration of heavy metals should not be determined.

[53] Cabinet Regulation No. 362 of 02.05.2006, Regulations Regarding the Use, Monitoring and Control of Wastewater Sludge and its Compost, Annex 1.

Test methods

The testing of samples of sewage sludge and its compost must be carried out by the methods (Table 33) shown in Annex 2 to MK Regulation No. 362 or by the latest methods accredited and used in accredited laboratories.

Table 33

Quality Indicators and Testing Methods to be Determined on the Average Sample of Wastewater Sludge and its Compost Series[54]

No.	Heavy metals	Methods *	
		for the preparation of samples	for testing
1.	Cadmium (Cd)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
2.	Chromium (Cr)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
3.	Copper (Cu)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
4.	Mercury (Hg)	LVS 346: 2005	LVS 346: 2005
5.	Nickel (Ni)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
6.	Lead (Pb)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
7.	Zinc (Zn)	LVS ISO 11466: 1995	LVS ISO 11047: 2003
8.	Environmental reaction (pH_{KCl})		LVS ISO 10390: 2002
9.	Amount of organic matter (%)		LVS ISO 10694: 1995
10.	Nitrogen (N) in dry matter (g/kg)		LVS ISO 11261: 2002
11.	Ammonia nitrogen (N-NH4) in dry matter (g/kg) by extraction of KCl		ISO/TS 14256-1:20 03 ISO 14256-2:20 05 (E)
12.	Phosphorus (P) in dry matter (g/kg)		LVS 398: 2002, EN 14672: 2005
13.	Dry matter (%)		LVS ISO 11465: 1993, LVS EN 12880

* Other methods of atomic absorption spectrophotometry may also be used, the limit values of which are not higher than 1 mg/kg – Cd; 12 mg/kg – Cr; 5 mg/kg – Cu; 12 mg/kg – Ni; 15 mg/kg – Pb; 0.2 mg/kg – Hg; and 10 mg/kg – Zn.

The dry matter content of sewage sludge shall be determined immediately after the sample has been collected, normally on site in the WWTP laboratory.

For the determination of the dry matter content of sewage sludge, the sample of sewage sludge shall be dried at a temperature of 100 to 105 °C to a constant mass. If the mass of the effluent sludge to be dried is squat, then after 4–5 hours the dried pieces must be carefully crushed to ensure that they are dried more quickly and evenly. Typically, a sample of sewage sludge dries up to constant mass within 10 to 12 hours[55].

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[54] Cabinet Regulation No. 362, Regulations regarding the Use, Monitoring and Control of Waste Water Sludge and Their Compost, Annex 2;

[55] I. Gemste, A. Vucan, "Sewage sludge", Jelgava: Agricultural University of Latvia, 2010–276 pp.

Inaccuracies allowed in determining the dry matter content of sewage sludge

- Samples of sewage sludge shall be collected not from fresh mass of sewage sludge but from the one that has been stored for a certain period and dried.
- The collected effluent sludge samples shall not be dried to a constant mass.
- For the calculation of the dry matter of sewage sludge, the dry matter content of agronomic indicators and heavy metals testing reports shall be used.

These samples have been dried during their storage, and the dry matter content in them is generally significantly higher than that of fresh sewage sludge.

For all the above errors, the calculated and reported dry weight of sewage sludge is higher than that of actually produced.

It is also important to ensure adequate sampling and transport of sewage sludge and its compost in order to ensure reliable and realistic results. In order to respect good sampling practices, it is necessary to take into account the following:

- for sludge samples, use only containers which cannot influence the results of the tests: glassware or plastic containers or sterile bags (particularly in cases where microbiological composition is to be analysed);
- the sampling equipment to take samples for microbiological analyses must be sterile (treated with a solution of 70–80 % alcohol, if it is of plastics, glass or metal, or treated with flame or boiling if it is of metal);
- when taking samples of dehydrated sludge, it must be verified that the sludge dewatering equipment has operated in normal operating mode for at least 30 minutes, the sludge sample must be taken at the place where the dehydrated sludge from the dewatering equipment falls in the conveyor, trailer, container or in the accepting chamber of the dewatered sludge pump;
- when taking compost samples, it must be verified that the composting process has been completed in the particular compost stud;
- it is recommended that samples of sewage sludge be delivered to the laboratory using cold boxes with frozen cold cells to ensure a transport temperature of 5 ± 3 °C;
- the samples taken shall be transported to the laboratory as soon as possible.

Record keeping

The sewage sludge producer shall record the mass, quality and use of each wastewater sludge series and enter the relevant data in a specially created registration journal in accordance with MK Regulation No. 362. On the basis of these records, the producer of sewage sludge and its compost shall draw up a quality certificate for each series of sewage sludge and its compost in accordance with the requirements of MK Regulation No. 362. A copy of the quality certificate shall be issued by the producer of sewage sludge and its compost to the user of sewage sludge and compost.

Separate accounting sheets shall be created in the registration journal, in which the following data shall be entered:

- the mass, quality and use of sludge from each series of sewage sludge produced during the reporting year (Annex 13 to MK Regulation No. 362);

- for the use (disposal) of sewage sludge produced in previous years in the reference year (Annex 14 to MK Regulation No. 362).

The register shall be kept for a period of not less than ten years. The producer of sewage sludge shall, in accordance with the data recorded in the register, prepare and submit a summary of the VVD:

- the mass, quality and use or disposal of sewage sludge produced in the reference year;
- the dry matter mass of the treated and untreated sewage sludge at the end of the reporting year, as well as the type of treatment of sewage sludge;
- the dry weight of the wastewater sludge produced in the reference year;
- the use or disposal of the mass of wastewater sludge produced in previous years but not used or disposed of in the accounting year, as well as its residues at the end of the accounting year.

Monitoring and control

Monitoring and control of the storage, use, disposal and monitoring of sewage sludge and compost in compliance with environmental protection requirements shall be carried out by the VVD.

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